TRANSACTIONS

of the American Society for Steel Treating

FEATURES

Service Annealing of Sling and Crane Chains —*William J. Merten* 193

Surface Cooling of Steels in Quenching —*H. J. French, G. S. Cook and T. E. Hamill* 217

The Manufacture of Acid Open-Hearth Steel for Forging Ingots —*H. P. Rassbach* 289

Stainless Iron and Its Application to the Manufacture and Transportation of Nitric Acid —*Dr. Walter M. Mitchell* 303

Further Observations on the Microstructure of Martensite —*Francis F. Lucas* 339

Constitution of Aluminum-Copper Alloys— *Prepared for the Recommended Practice Committee* 368

Vol. XV No. 2
February, 1929

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TRANSACTIONS
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VOL. XV FEBRUARY, 1929 NO. 2

SERVICE ANNEALING OF SLING AND CRANE CHAINS

By William J. Merten

Abstract

This paper discusses the inconsistent results in ductility and strength that are ordinarily obtained when chains are annealed at temperatures unsuited for links that have been severely deformed and cold-worked in service. The author recommends a uniform recrystallization at temperatures considerably above the transformation range to render the chain entirely safe for further service without resorting to a reduction of the safety load and basing the calculation of permissible stresses on the average cross sectional dimensions only.

Introduction

THE correct temperature range for the periodic reannealing of chains for elimination of local or partial hardening of links on acount of severe cold work on the surface or external portion of the links has been and is still the subject of discussions of controversial aspect. This paper discusses the various factors involved and through experimental evidence, the results of which are given, described and illustrated, points out the advantages of the use of normalizing temperatures for uniform adjustment of the grain structure of the irregularly strained links and other parts of the chain. It also shows the need for a practice based upon complete recrystallization of the iron or steel parts at a higher

The author, W. J. Merten, a member of the society, is metallurgical engineer with the Westinghouse Electric and Manufacturing Company, East Pittsburgh. Manuscript received June 22, 1928.

temperature range than is in use today for this purpose. This proposed practice will permit the loading of the reannealed chain based upon the minimum cross sectional dimension, giving, however, due consideration to surface condition, but takes no account of length of service or other fictitious reasons for deteriorations such as age or number of reheatings.

High Temperature Versus Low Temperature Reannealing of Chains

The first annealing of chains after forming and forge welding of links is practically universally conducted at a temperature

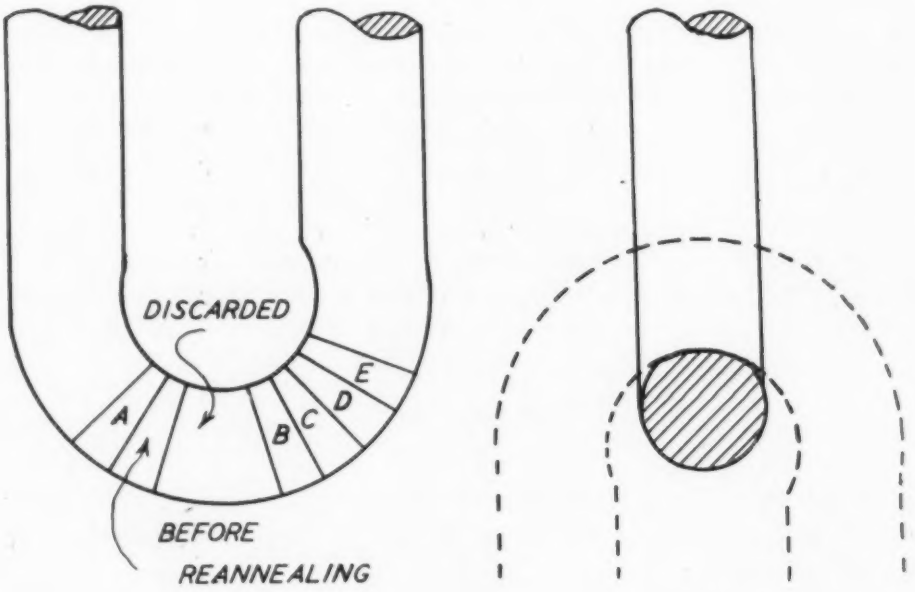

Fig. 1a. Fig. 1b.

Fig. 1—Sketch 1a Shows the Location from which Samples Were Taken on Chain Links for Microscopic Examination of Grain Structure. Fig. 1b is a Diagram Showing the Manner in which Chain Links are Worn and Cold-worked in Service.

above the Ac_3 critical point or above the alpha-gamma change of the chain material whether wrought iron or steel. It is well recognized that entire or complete recrystallization of the iron after being held at the forge welding heat is needed for uniform grain refinement, and for satisfactory structural conditions for safe performance of the chain, but even here it has been shown that the temperature range of 1650 to 1700 degrees Fahr. is not high enough

unless the hot working or finish forging of the link has been continued down to or below this critical Ar_3 temperature.[1]

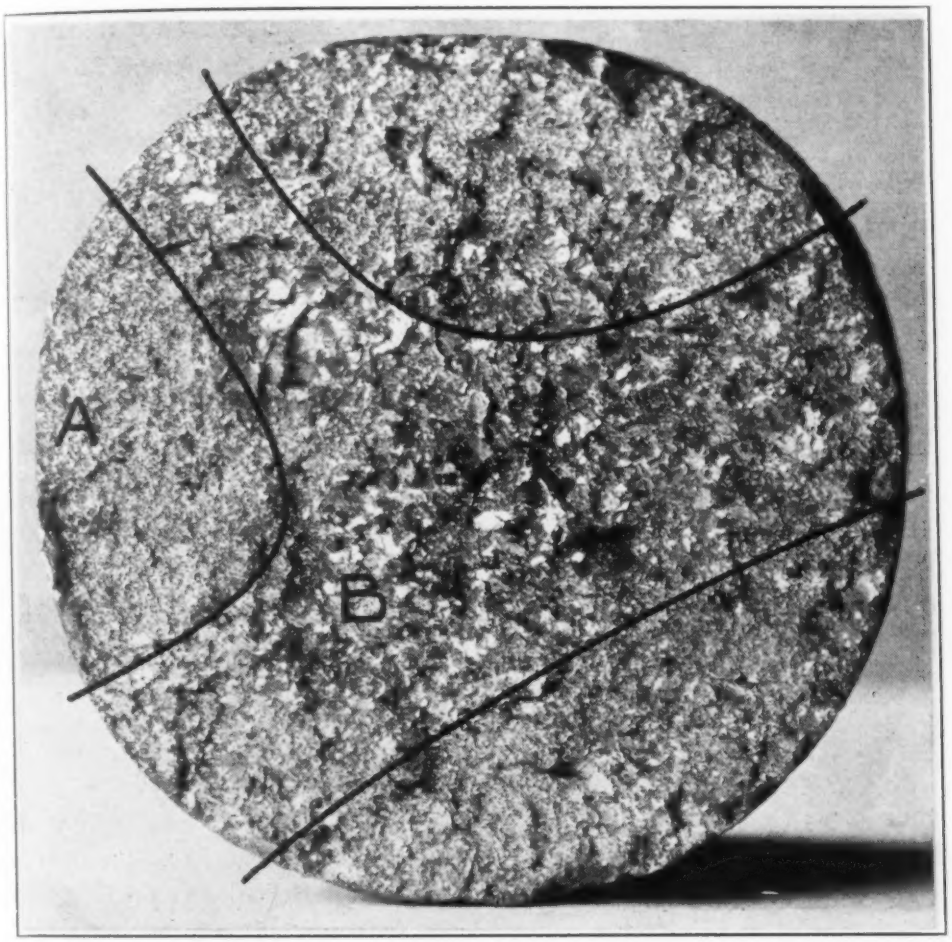

Fig. 2—Photograph of a Cross-section of a Chain Ring Fracture Showing the Manner in which the Grains Vary in Size Due to Cold Working and Overstraining. × 1½. (A) Fibrous Structure. (B) Coarse-grained Structure.

The cold work to which the links are subjected during service, especially on the inner curved surface of the link, causes a plastic flow of metal to occur, as shown in Fig. 1a. When such plastic deformation has taken place, subsequent loading on this somewhat embrittled material imposes a decided localization of stress and still further cold work hardens and embrittles the metal. This produces a surface layer of metal containing minute cracks or cen-

[1]W. J. Merten, "High Temperature Treatments of Castings and Forgings as Evidenced by Core Drill Tests from Heavy Sections," TRANSACTIONS, American Society for Steel Treating, Vol. XIII, January, 1928, p. 1.

ters of incipient failure under even very moderate stress application.

The annealing of an iron chain in a temperature range favorable to grain growth for this cold-worked section and holding it at this temperature induces a partial recrystallization of the cold-worked portion only, while the rest of the cross section is not affected materially. When a critical grain size has been reached actual intercrystalline separation may and probably does occur. This is then probably the cause of sudden failure of chain links at very low stresses when exposed to low temperatures around 0 degrees Fahr. It is quite common in large chain link sections (above 2 inches in diameter) that a service failure exhibits a fracture in which part of the break is coarsely granular or intercrystalline, changing into a fibrous intracrystalline one, and again into a less coarse granular portion and finally again into a fibrous section. With a little conjecture, a history of the sequence of hot and cold work and subsequent heating operations may be fairly accurately given. See Fig. 2.

Experiments

Experimental evidence in support of what has been said above was obtained as follows:

From three chain links which showed considerable wear and cold work, a section was cut from the worn portion as shown in Fig. 1a and marked 3, 4 and 5. Photomicrographs were prepared. Figs. 3 to 5 show the structure before reannealing at a magnification of 100 diameters. The links were then heated to 1200 degrees Fahr. and held at this temperature for 1 hour and cooled in air. Sections were then cut from the links at location A and prepared for microscopic examination. Figs. 6 to 8 show the resulting structure at the cold-worked edge. There is little if any evidence of change in grain structure resulting from an annealing at this temperature. A benefit, therefore, is certainly questionable. The remaining goose neck portion of the links was then reheated to 1300 degrees Fahr. held at this temperature for 1 hour, then air-cooled and sections marked B (Fig. 1a) cut from it for microscopical examination of change of grain structure at and near worn edge. Photomicrographs shown in Figs. 9 to 11 illustrate the apparent beginning of a crystal growth. In Fig. 12, however,

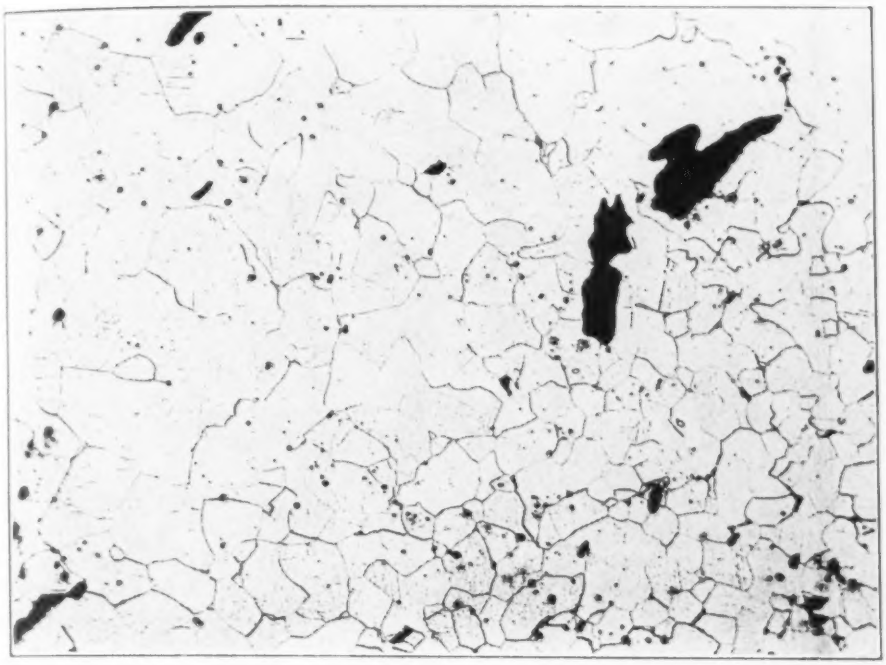

Fig. 3—Photomicrograph Showing the Grain Structure of Chain Link Before Reannealing. Photomicrograph Taken Near the Edge of the Worn Link Section. × 100.

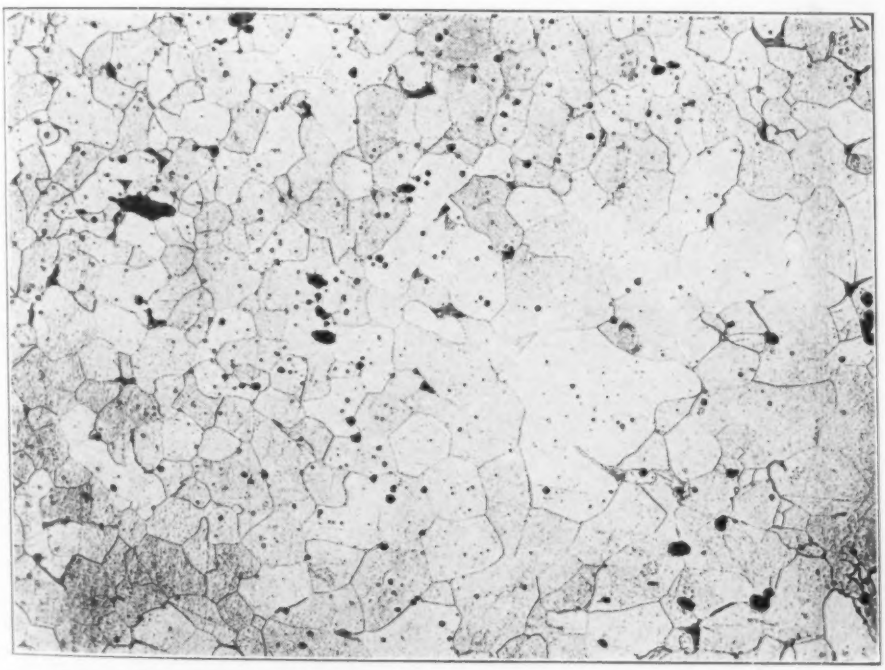

Fig. 4—Photomicrograph Showing the Grain Structure of Chain Link Before Reannealing. Photomicrograph Taken Near the Edge of the Worn Link Section. × 100.

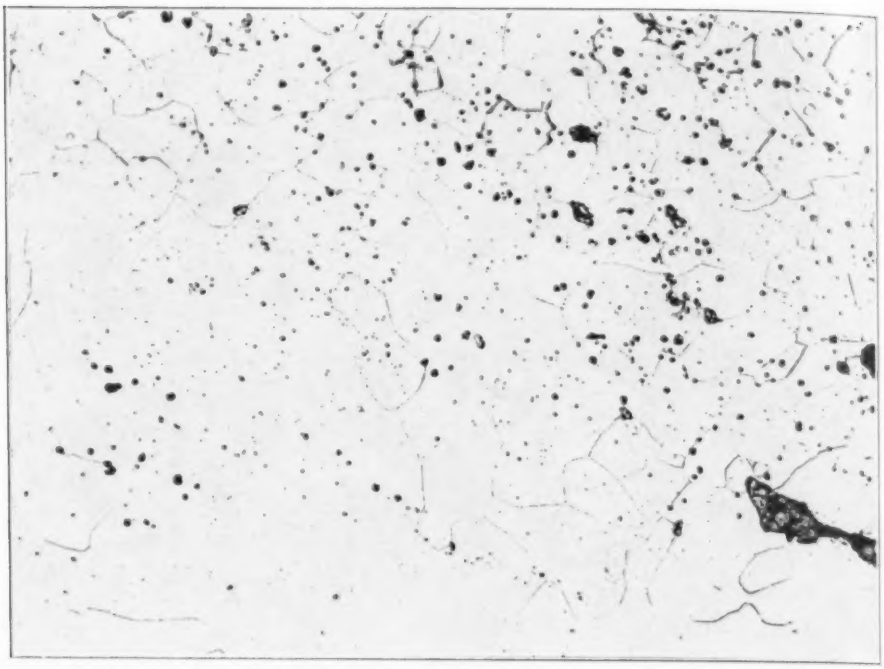

Fig. 5—Photomicrograph Showing the Grain Structure of Chain Link Before Reannealing. Photomicrograph Taken Near the Edge of the Worn Link Section. × 100.

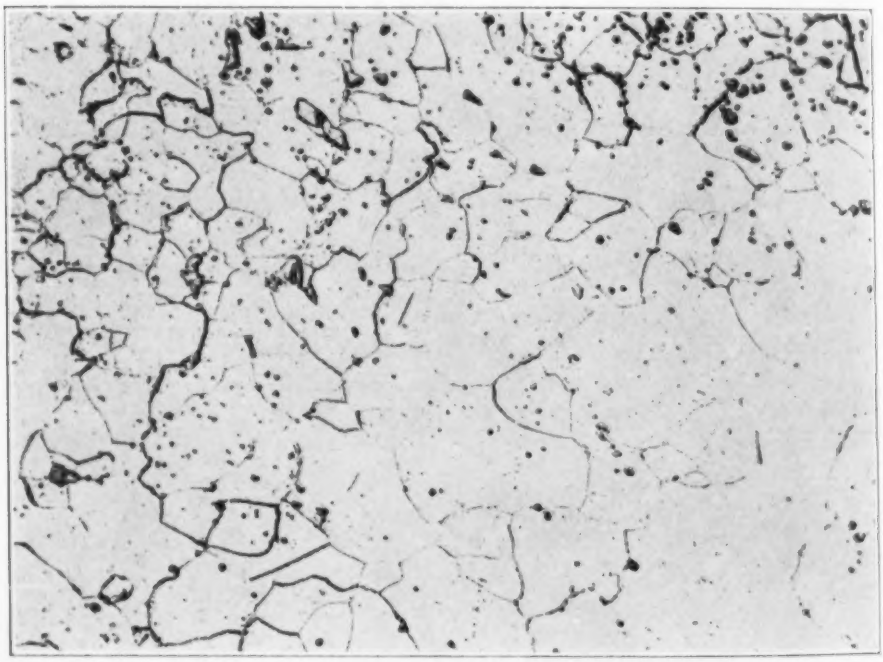

Fig. 6—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1200 Degrees Fahr. It will be Noted that there is Practically no Change in the Structure after Holding the Wrought Iron Link at this Temperature for One Hour. × 100.

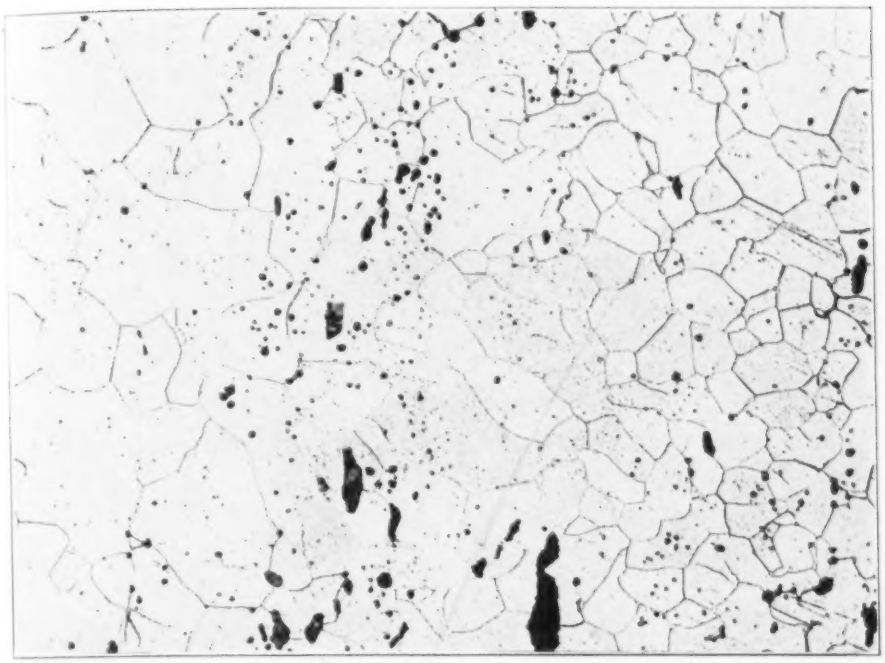

Fig. 7—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1200 Degrees Fahr. It will be Noted that there is Practically no Change in the Structure after Holding the Wrought Iron Link at this Temperature for One Hour. × 100.

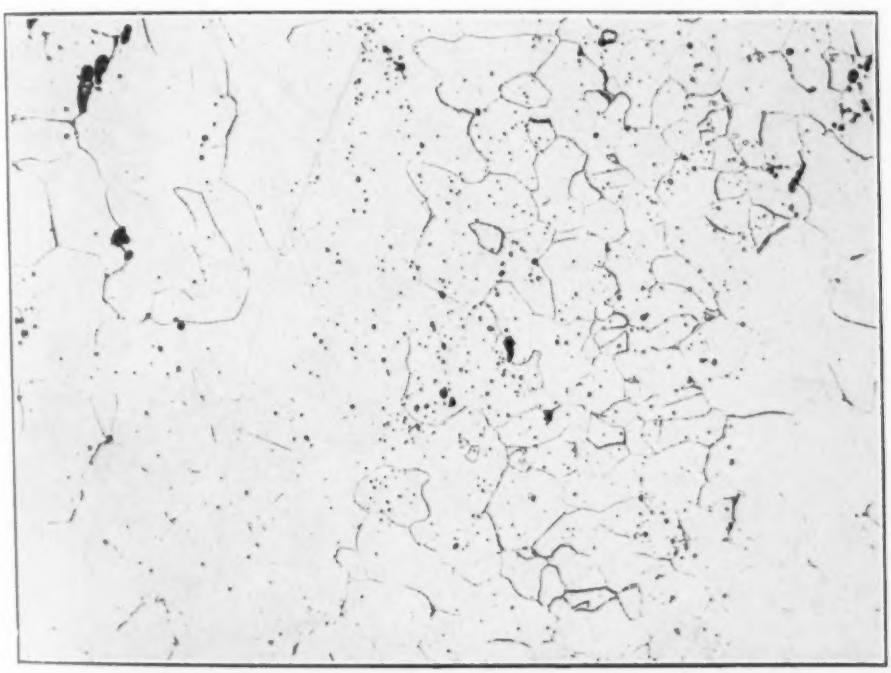

Fig. 8—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1200 Degrees Fahr. It will be Noted that there is Practically no Change in the Structure after Holding the Wrought Iron Link at this Temperature for One Hour. × 100.

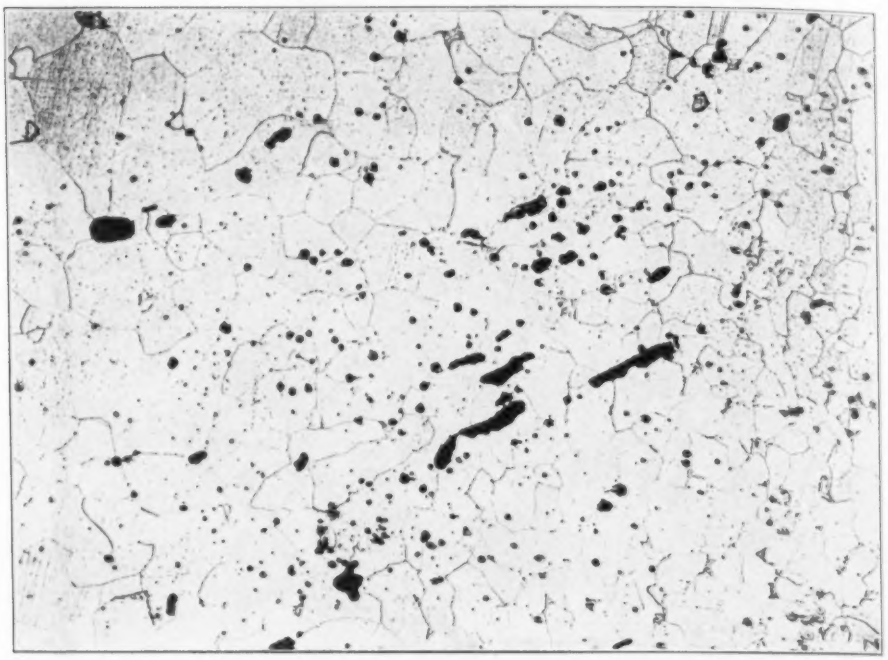

Fig. 9—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1300 Degrees Fahr. It will be Noted that there is Little if any Change in the Structure after Holding the Wrought Iron Link at this Temperature for One Hour. × 100.

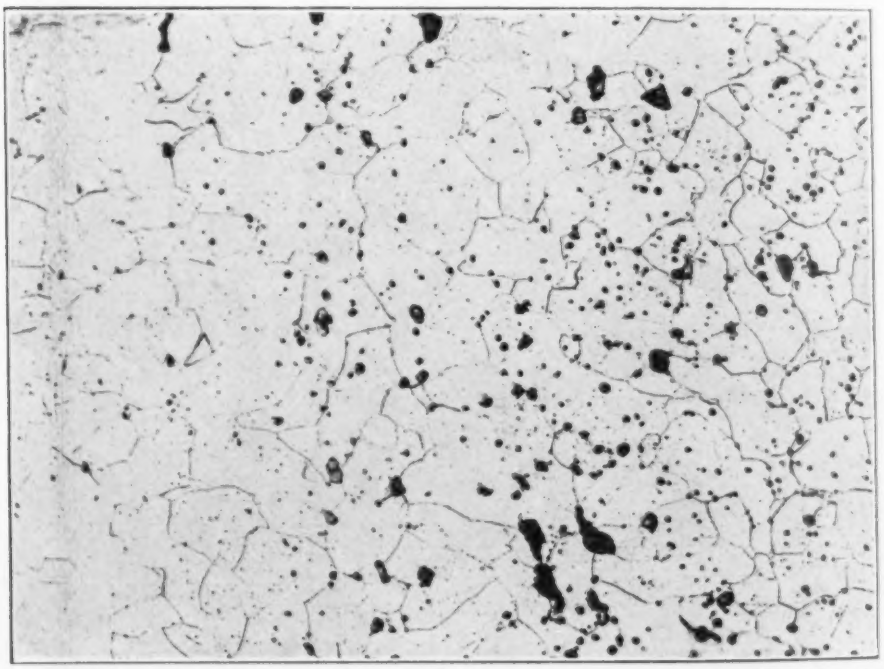

Fig. 10—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1300 Degrees Fahr. It will be Noted that there is Little if any Change in the Structure after Holding the Wrought Iron Link at this Temperature for One Hour. × 100.

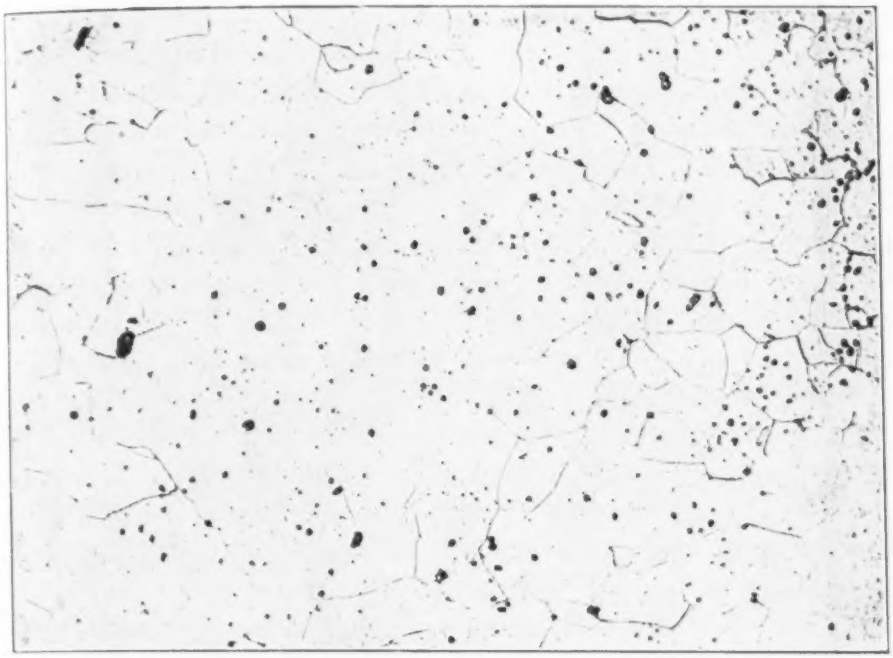

Fig. 11—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1300 Degrees Fahr. It will be Noted that there is Little if any Change in the Structure after Holding the Wrought Iron Link at this Temperature for One Hour. × 100.

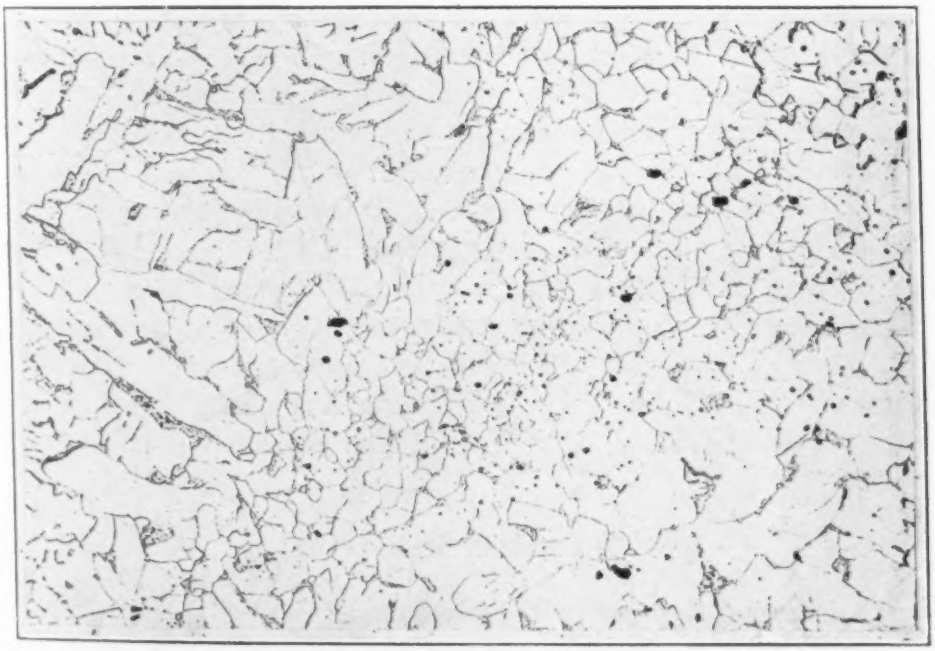

Fig. 12—Photomicrograph of the Mid-Section of a Chain Link After Reannealing at 1300 Degrees Fahr. It will be Noted that there is no Change in the Grain Structure. × 100.

a picture of the grain structure at midsection does not show any change. The link parts were then reheated to 1400 degrees Fahr. held at temperature for 1 hour, air-cooled and machined for microscopic examination. The location from which these samples were taken is marked C in sketch (Fig. 1a). Photomicrographs shown in Figs. 13 to 15 illustrate the change in grain structure clearly, a decidedly severe growth having taken place. This is the temperature in most cases recommended for service reannealing of strained chain and deserves close attention and will be referred to again later. The links were next heated to 1700 degrees Fahr. held there for 1 hour and air-cooled. Samples for microscopical examination were cut from location marked D in sketch (Fig. 1a). Photomicrographs, Figs. 16 to 18 are representative of the structure due to a reannealing at normalizing temperature which is the practice advocated somewhat reluctantly by the American Society for Steel Treating Recommended Practice Committee. It will be noticed that the refinement or recrystallization is only partly completed and only in the cold-worked or worn portion while the more centrally located sections are now in the range of grain growth.

The links were then taken and reheated to 1900 degrees Fahr. held at temperature for 1 hour, cooled in air, and samples cut from links at location marked E (Fig. 1a) for examination of grain structure. Figs. 19 to 21 are photomicrographs of the grain structure of these samples and show a practically uniform refinement and complete recrystallization. This refinement and uniformity of adjustment can be carried still farther by again reheating to a normalizing temperature of 1700 degrees Fahr. and air cooling followed by a reheat to 1250 degrees Fahr. and slow cooling for relieving of strains introduced by the air quench. This will then give a chain which can be again put into service under the same general loading schedule as a new chain, stress calculation requiring consideration of minimum diameter of cross section only.

Discussion of Results

Discussing the results it seems quite evident that the annealing of chains requires further study of the effect of higher than normalizing temperature around 1700 degrees Fahr. in order to elim-

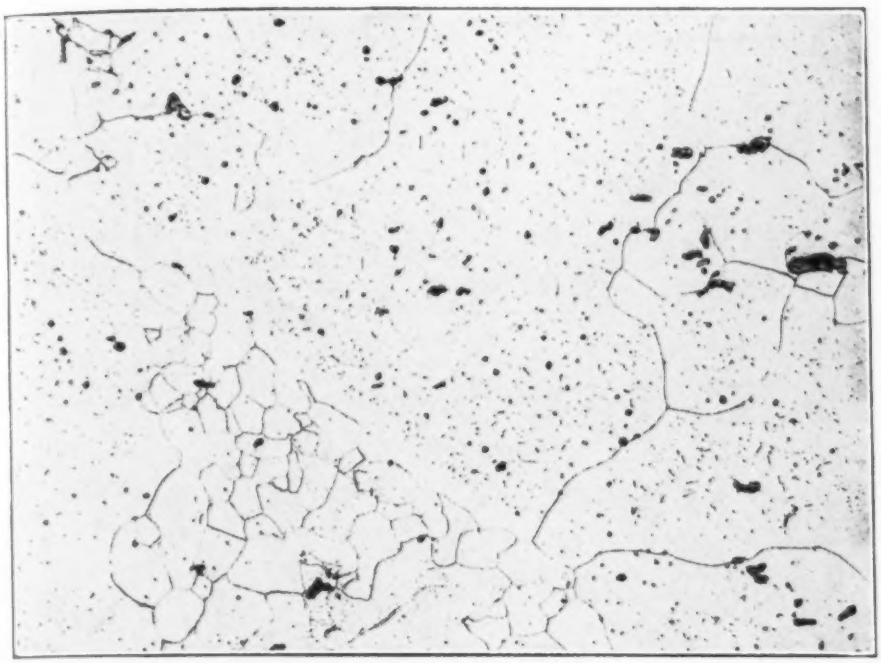

Fig. 13—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1400 Degrees Fahr. It will be Noted that a Pronounced Grain Growth has Taken Place. This is a Result which is to be Expected in Most Cases in the Majority of Shops at Present, Since Chain Annealing is Conducted at this Temperature. × 100.

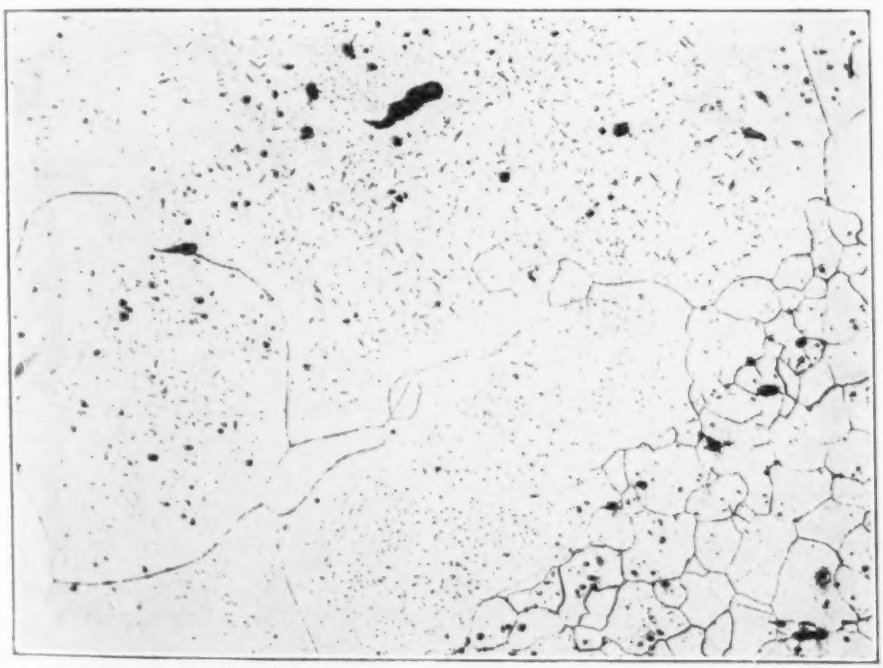

Fig. 14—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1400 Degrees Fahr. It will be Noted that a Pronounced Grain Growth has Taken Place. This is a Result which is to be Expected in Most Cases in the Majority of Shops at Present, Since Chain Annealing is Conducted at this Temperature. × 100.

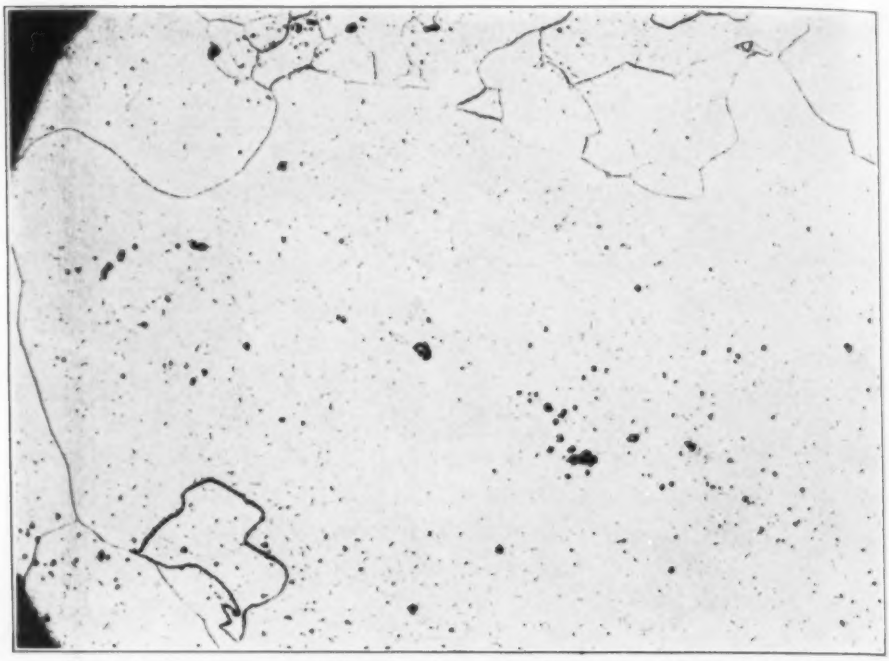

Fig. 15—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1400 Degrees Fahr. It will be Noted that a Pronounced Grain Growth has Taken Place. This is a Result which is to be Expected in Most Cases in the Majority of Shops at Present, Since Chain Annealing is Conducted at this Temperature. × 100.

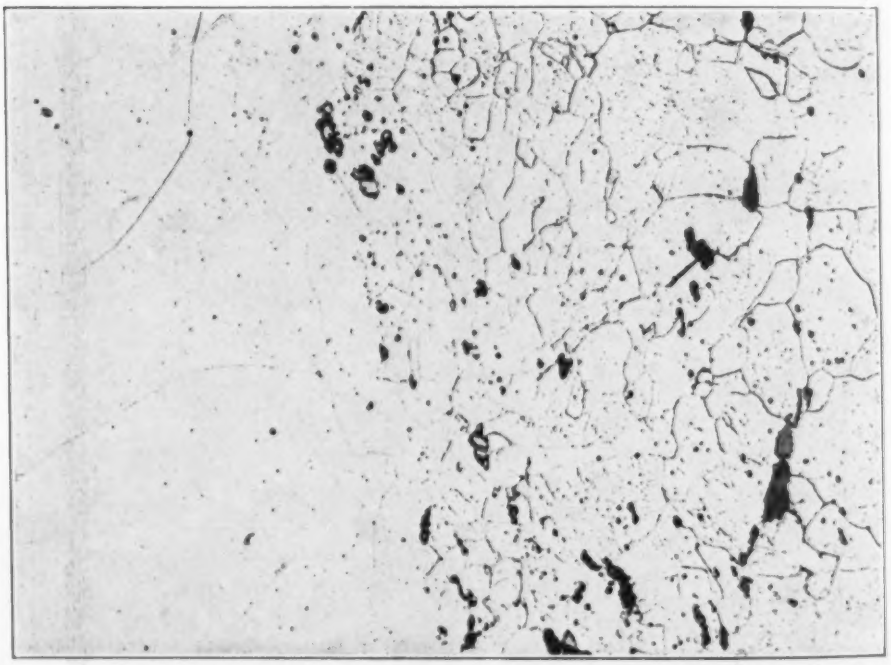

Fig. 16—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1700 Degrees Fahr. It will be noted that the Refinement of Structure is not Completely Uniform and Shows that a Temperature Higher than 1700 Degrees Fahr. Must be Applied for Complete and Uniform Refining. × 100.

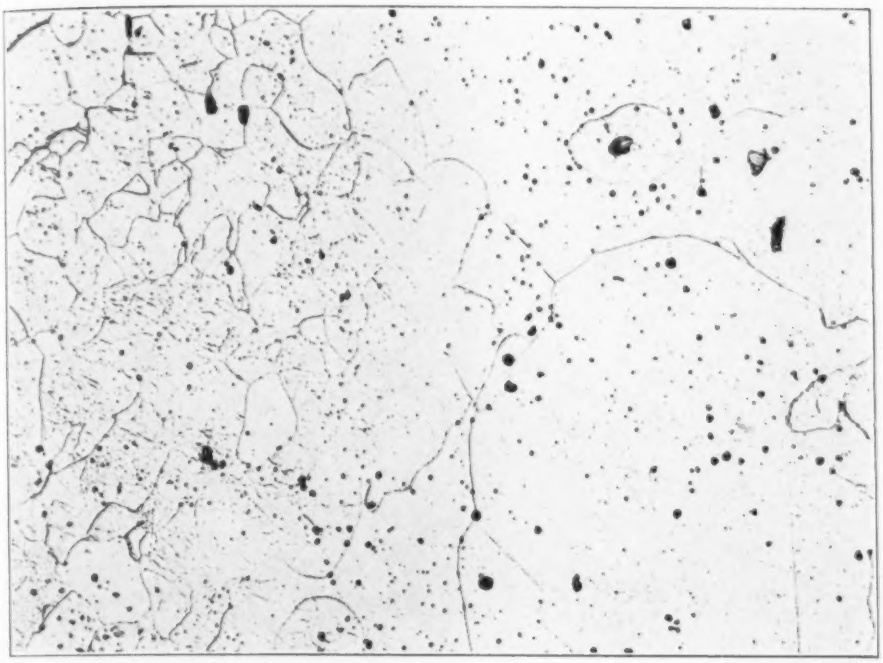

Fig. 17—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1700 Degrees Fahr. It will be noted that the Refinement of Structure is not Completely Uniform and Shows that a Temperature Higher than 1700 Degrees Fahr. Must be Applied for Complete and Uniform Refining. × 100.

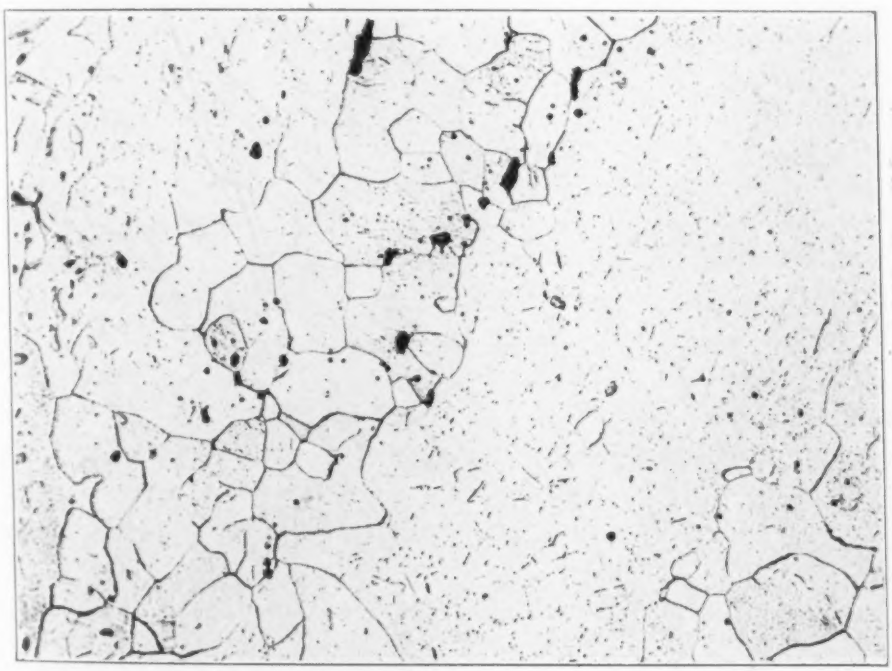

Fig. 18—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1700 Degrees Fahr. It will be noted that the Refinement of Structure is not Completely Uniform and Shows that a Temperature Higher than 1700 Degrees Fahr. Must be Applied for Complete and Uniform Refining. × 100.

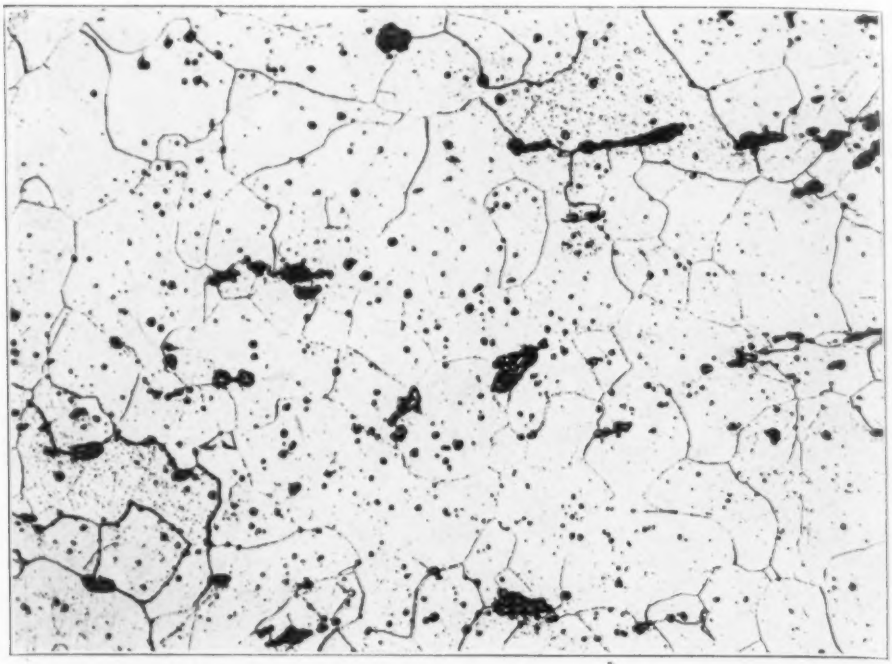

Fig. 19—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1900 Degrees Fahr. It will be noted that there is a Complete and Uniform Adjustment of Grain Structure as a Result of this Treatment. × 100.

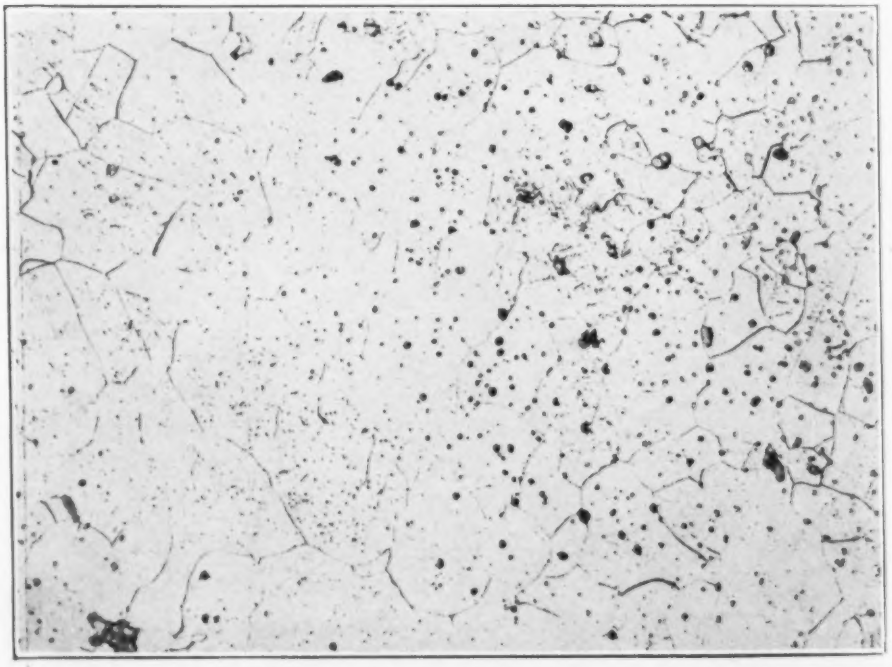

Fig. 20—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1900 Degrees Fahr. It will be noted that there is a Complete and Uniform Adjustment of Grain Structure as a Result of this Treatment. × 100.

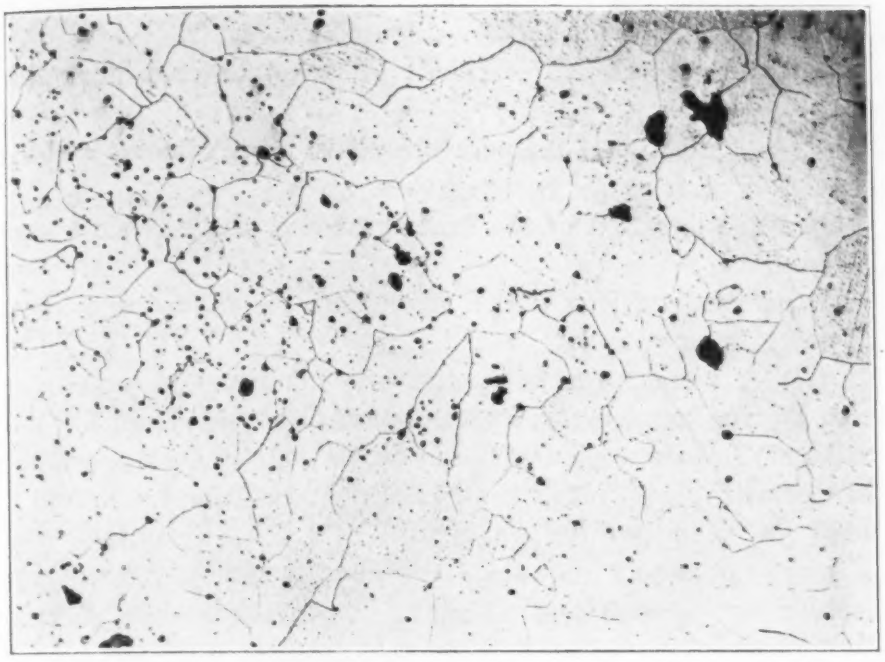

Fig. 21—Photomicrograph Showing the Grain Structure of Chain Link After Reannealing at 1900 Degrees Fahr. It will be noted that there is a Complete and Uniform Adjustment of Grain Structure as a Result of this Treatment. × 100.

inate the element or factor of guessing in recommending safe loading of chains after annealing.

It also appears from these experiments and previous work of the author that in steels and irons in which the nonmetallic constituents are of such percentage as to influence materially the strength, ductility and other physical properties that higher temperatures than now in vogue for annealing are required to uniformly refine the grain structure and obtain a degree of ductility satisfactory for safe performance of chains under conditions encountered in shop service. Low temperature service reannealing can only be recommended where the overstraining is known to be very slight and wear or cold work is not in evidence and therefore a strain-relieving heat is all that is required for safety assurance.

Summary of Experimental and General Evidence

An analysis of the results of the experimental and general evidence presented here indicates that the factors involved in a complete reconditioning of a worn chain by reannealing are the following:

1. The degree of refinement of grain structure from the original heat treatment of forge welded chain.

2. The degree of plastic deformation or cold work during service.

3. The degree of temperature above the Ac_3 point and rapidity of cooling from this temperature.

4. The duration of the heating at and above critical temperatures.

In concluding I offer as a suggestion the following heat treating practice for chains.

Heat treatment after forging—heat uniformly to above the finish forging temperature (1900 degrees Fahr.). Hold for 1 hour per inch of cross section of largest part of chain (ring or hook). Then cool in air to black heat (700 degrees Fahr.). Reheat uniformly to just above the Ac_3 point—hold for 1 hour then cool in air to approximately 1000 degrees Fahr., then slowly to room temperature.

For Service Annealing

Heat chain uniformly to above the Ac_3 temperature for complete recrystallization. Hold for at least 1 hour at temperature and cool in air to a black heat of 700 to 800 degrees Fahr. Then slowly to room temperature. The first part of this practice is not in general use and has been given little if any attention whatever and its performance contributes probably more to the life and performance of a chain than even the selection of the most suitable material. The complete success of the service annealing practice depends somewhat upon the attention given the chain during the first heat treatment and if definite information regarding heat treating practice after forming and forge welding of chain is not at hand, a high temperature treatment for refining becomes imperative.

Finally, I hope to have aroused sufficient interest among those particularly involved in annealing of chains to further investigate a complete and uniform refinement of grain structure of used chains by reannealing at high temperature followed by heating for normalizing and finally followed by a heating for strain removal.

Acknowledgment

Acknowledgment is herewith given for the assistance given

by O. W. Ellis and Miss Ferguson of our research department, and W. L. Snyder of the M. and P. Engineering Department, in the preparation of the samples for photomicrographical work.

DISCUSSION

Written Discussion: By C. G. Lutts, metallurgist, Boston Navy Yard.

The author's recommended high temperature for periodic annealing of chain is apparently based largely on results of grain size studies. While it is true that annealing of chain above the Ac_3 point will correct cold work and eliminate any possibility of gross crystallization, still, no test data or proof is offered that low annealing temperatures will not give the same desirable practical result—that of freeing chain from brittleness. It is a fact that the practice of low temperature annealing of chains has been in effect for some years and that the results are generally satisfactory.

There is one very practical objection against long soakings above the Ac_3 point. At such high temperatures the metal of chains oxidizes and wastes away rapidly. Frequent treatments at these temperatures are known to seriously shorten the useful life of chain because of the rapid decrease in wire diameters and an excessive softening of the metal.

The author lays stress on the feature of gross crystallization, which he shows can be developed, as was the case with one of his low temperature annealing treatments. It seems, that principally, because of this, he prefers the high temperature treatment. That gross crystallization is an undesirable structure is admittable, but, that gross crystallization is unavoidable or even when present and as present it constitutes a serious weakness is not proved. In other words, the choice is between the costly and very severe high temperature treatment and the possibility that gross crystallization, if developed with low temperature annealing, might be found weakening. Too, the author himself shows by photomicrographs that the 1200 and 1300 degree Fahr. low temperature anneals do not cause gross crystallization, although, as is well known in this connection, the severity of cold work determines the beginning of recrystallization and the temperature at which gross crystallization sets in. However, the temperature range 1200 to 1300 degrees Fahr. is the one successfully used today for the periodic annealing of chain and instances of serious gross crystallization are not reported.

The author doubts whether a benefit results from a 1200 to 1300 degrees Fahr. anneal because there results little change in grain structure. This is open to question since it is well recognized that with metals in general a considerable amount of internal stress may be relieved before there is any noticeable change in the grain structure.

Finally, is the matter of failure of chains and hooks and the erratic nature of these occurrences a simple matter of grain structure and work hardened surfaces? It has been pertinently asked, elsewhere, that if this be true, how is it easily explained that hundreds of industry's case hardened articles give such reliable service. Or, are the erratic failure of chain more

reasonably explained on the basis of internal stress plus lack of ductility in the work hardened surface plus the added stress, possibly of a normal working load, which altogether and at the right point exceed the strength of the metal and the article breaks? And does the delicate balance between these internal stresses and their ready susceptibility to intensification or relief explain these too well known erratic failures? In the reviewer's opinion, the successful attack on the problem of chain failure and on corrective heat treatments is to be led with a study of and a better understanding of internal stress, which unseen, is developed by those same agencies which have made the work hardened surface layers the subject under examination today.

Written Discussion: By Lieutenant Commander H. N. Wallin, Construction Corps, U. S. Navy, Bureau of Construction and Repair, Navy Department, Washington, D. C.

The Bureau of Construction and Repair of the Navy Department has conducted considerable research and experimentation on the subject of annealing of chains. The Navy's first experiments along this line were undertaken at the Boston Navy Yard in 1914 for the purpose of determining the best heat treatment for wrought iron links after fabrication. Most of the tests were made in connection with anchor chain inasmuch as the amount of crane chain used in the Navy is negligible as compared to the amount of anchor chain used. Until a few years ago all the Navy's anchor chain was made of wrought iron but recently a large part of it has been made of high carbon cast steel, and therefore most of the tests and experiments have been made on anchor chain manufactured of these two materials. No doubt the results of such investigations are applicable to crane chain and chain used for miscellaneous purposes when such chain is manufactured of wrought iron or high carbon cast steel.

Mr. Merten's statements in regard to the cold-working of chain in service with consequent local embrittlement and eventual failure of chain links are noted with interest, as his views are substantiated by Navy experience. There have been numerous occasions where wrought iron chain links of 2¾-inch wire have fractured when subjected to very small loads, or in some cases when merely dropped from a height of fifteen or twenty feet upon a concrete floor. Usually cold working is accompanied by a reduction in the mean diameter of the chain links due to the plastic deformation described by Mr. Merten. It has been the Navy's practice to condemn the chain as far as its use as anchor chain is concerned when this reduction, whether due to cold working or to abrasion, reaches 10 per cent of the original diameter of the links.

Periodic annealing of wrought iron anchor chain has been practiced in the Navy for a number of years, and it has been found that relieving of stresses by annealing has greatly reduced failures of anchor chains. The combined annealing and heat treatment of chains as proposed by Mr. Merten would no doubt be beneficial, and his viewpoints are considered essentially correct. It would not be amiss to warn those interested in this subject that annealing or heat treatment is not a panacea; such treatment

will not reconstruct or restore chain which has been excessively deformed by stresses beyond the elastic limit.

In regard to heat treatment of wrought iron chain, it has been determined that high temperatures are required to relieve the stresses induced by processes of manufacture. For a high grade double refined iron it was found that best results were produced by heating the chain to 1760 degrees Fahr. and holding it at that temperature for about 10 minutes, and then cooling it in air; lower temperatures resulted in weaker and less satisfactory chain, and higher temperatures appeared to offer no additional improvement. In the periodic re-annealing of wrought iron chain, previously referred to, it has been found that best results are obtained by heating to 1292 degrees Fahr., holding it at that temperature for three hours and then cooling it in air or in the furnace. It is not known for a certainty that re-annealing at higher temperatures would not give better results, but it is understood that investigations have been made by the German Admiralty on this point. The German Admiralty seems to believe that temperatures from 1112 to 1202 degrees Fahr. produce the best results, while higher temperatures not only fail to give better results, but cause considerable wastage of metal due to scaling. Six hours is considered by them to be the best period of time for this heat treatment; longer heriods have no additional benefits.

The cast steel anchor chain used by the Navy is of high carbon and high manganese content. It has been found that for this particular steel the best heat treatment consists of raising the temperature to 1650 degrees Fahr., water quenching for about a minute and drawing to 1100 degrees Fahr., and holding at that temperature for about two hours. It is not the practice of the Navy to periodically re-anneal cast steel anchor chain, chiefly for the reason that the stresses to which such chain is subjected in service are well below the elastic limit of the material.

It is believed that a large part of industrial chain is steel chain, and would, therefore, be susceptible to a heat treatment somewhat different than the Navy employs for wrought iron chain. It has been the Navy's experience that the responsiveness of chain cable to various temperatures depends to a large extent upon the chemical composition of the material of which the chain is made. It would appear that this question of chemical composition is very important in arriving at a satisfactory procedure for heat treatment of chain and should be given careful consideration in the valuable work now being undertaken by the National Safety Council and others on this subject.

Written Discussion: By F. G. Frisbie, Duquesne Steel Foundry Co., Coraopolis, Pa.

I have read over Mr. Merten's paper carefully and have digested it to the best of my ability and desire to make several comments relative to our own shop practice and to ask a question or two.

In our own shop the problem of annealing crane chains has been held in abeyance. We have made only a few attempts to anneal them within the past six years. Information obtained from our source of

supply always indicated that heating over 1450 degrees Fahr. would be ruinous. It is a fact that we have had more chain trouble after our attempted annealings than we had before them. 95 per cent of our chains are wrought iron and the links apparently lost their rigidity after being heated to 1400 degrees Fahr. This caused an elongating of the links and subsequent uneveness in the length of the chains which we use in sets of two, four or eight, of course necessitating a trip to the blacksmith as the chains must be uniform lengths to carry loads in a horizontal plane.

We have had very little trouble with the links breaking. Overloading stretches the links beyond the yield point causing the unevenness of length just mentioned. Mr. Merten's paper would indicate that his recommended treatment would restore the metal to its original structure. Variation in quality of iron used to give us considerable trouble until we centered our purchases upon one manufacturer. Undoubtedly any two brands of high grade chain iron could be made structurally identical by this treatment.

Although not specifically stated in this paper, I wonder if Mr. Merten does not believe that at least one cause for the benefits derived from this treatment is the more even distribution of slag particles, particularly noticeable in photomicrograph 14, obtained by the high temperature treatment. I would like to ask Mr. Merten what benefits, if any, other than the complete recrystallization, does he attribute to this treatment.

Written Discussion: By Dr. A. V. deForest, American Chain Co., Bridgeport, Conn.

This paper on the annealing of iron chain again emphasizes the difficulty of gathering experimental evidence on such a variable material as wrought iron by means of only one line of attack. By using a microscope on pieces of three chain links, none of them shown to be in a brittle condition, Mr. Merten effectively disposes of the recommendations made by Gough and Murphy of the National Physical Laboratory after four years work comprising hundreds of impact tests on full size specimens.

If all those who are interested would procure from His Majesty's Stationery Office, 16 Old Queen Street, Westminster, S. W. 1, Engineering Research Special Report No 3, price 7s. 6d. on the "Causes of Failure of Wrought Iron Chains," the uncertainty which seems to exist on the subject would to some extent be clarified.

There are two different phenomena to be considered, one, the effect of wear and overload producing deformation, the other an embrittlement without any appreciable change in the appearance or dimensions of the chain. This latter effect was discovered in the course of the National Physical Laboratory's investigation of the whole problem. It is described by Gough and Murphy in their summary as follows:

"This brittleness was shown to be due to a 'skin' effect, caused by surface hardening resulting from small impacts. The deleterious effect of this action is undoubtedly the major cause of the production of brittleness in wrought iron chains. The evidence obtained in the course of the work indicates that, as the result of inter-link action, hammering on ground, rattling through hawse pipes, battering on chain wheels, cleaning by rum-

bling machines (in certain cases), the material of the surface of the link—in some cases only to a very small depth—becomes locally hardened to such an extent that its ductility is practically exhausted. The link surface then consists of a thin, highly brittle case covering a core possessing the ductile properties of best chain iron. When the link section is subjected to bending strains—particularly those caused by shock conditions—the hardened skin strains elastically and then cracks. This crack is of such a type that very great stress concentration occurs at its root. When the crack reaches the underlying ductile metal, the latter cannot exert its property of ductility because of the prevailing conditions of local constraint and the crack continues its course throughout the entire section of the link producing a fracture which has an entirely brittle (apparently coarsely crystalline) appearance throughout.

"This type of fracture has been encountered during tests on chains drawn from service, and has also been produced on new chain iron bar and new chain links which have been lightly hammered in the laboratory.

"Heat treatment—low temperature annealing or normalizing—has been shown, by causing re-crystallization in the hardened surface layers, to restore the original ductility."

On the matter of a statement by Mr. Merten: "Low temperature service re-annealing can only be recommended where the overstraining is known to be very slight and wear or cold work is not in evidence, and therefore a strain relieving heat is all that is required for safety assurance." I fail to see any need of strain relief in such material as wrought iron, but here are a few figures in the case of heavy overstrain. Nineteen tests on full size chain were made in duplicate, covering nineteen different combinations of repeated heavy overstrain, normalizing at 1832 and annealing at 1202. Single overstrain followed by annealing or normalizing, double overstrain and triple overstrain also followed by annealing or normalizing, as well as a heat treatment following each overstrain led to the following conclusions.

"If a chain is overstrained statically, either in one operation or a number of operations, with intermediate heat treatment, to an extent of the energy absorbed up to and including 50 per cent of the original energy value of the chain, then, provided a final heat treatment is administered, the remaining energy to fracture in the final destruction test is at least equal to, and nearly always greater than, the original energy content. Either low-temperature annealing or normalizing will produce this result."

The important statement is as follows:

"As a result of the present research, it is concluded that chain failures in service are not due to the effects of heavy static overstraining, but rather to surface embrittlement caused by local impacts. With regard to static overstraining, it has been shown that neither subsequent low-temperature annealing nor normalizing produces any deleterious effects on the properties of the chain, but actually effects an improvement, particularly in the case of normalizing. With regard to the embrittlement caused by local impacts, both heat treatments are practically equally efficacious as restorative

processes. Generally speaking, normalizing is preferable. On the other hand, we have noticed many cases of chain links and chain iron bar which have split along the piling when normalized. Also greater wastage from scaling naturally occurs at the higher temperature. It has also been shown that as the temperature rises over 1200 degrees Cent. the symptoms of overheating—with accompanying brittleness—appear. It is apparent, therefore, that a normalizing process applied to chains must necessarily be much more carefully conducted than a low-temperature annealing treatment. These facts must be carefully considered in prescribing a suitable heat treatment to be used as a restorative process for chains in service.

"It is obvious that some heat treatment is necessary and that from the point of view of the small user of chains, this treatment must be inexpensive, must not demand any special plant additional to that already available, and must be largely "fool-proof."

In view of these facts, it is suggested that the present practice of low-temperature annealing be retained; further, that where it is not at present practiced, such practice should be made obligatory."

It is heartily agreed that where conditions admit of Mr. Merten's recommendation to "heat uniformly above the Ac_3 point," can be intelligently followed, that procedure is quite correct. In the general case, a dull red heat is more easily attained, and as Gough says, more fool-proof.

Written Discussion: By Alvan L. Davis, Scovill Mfg. Co., Waterbury, Conn.

The experience of the Scovill Manufacturing Company may be of interest. Wrought iron chains are used on electric pan pullers to draw loads into and out of annealing furnaces. The chains have to be dragged over the floor by hand, and are heavy to handle, therefore we use as small size chain as possible. Hence chains are worked up to their safe working strength. In dragging a pan 5 feet wide by 12 feet long over an uneven hearth, there are unavoidable jolts and jars, which subject the chain to shocks. Failures are not due to stretching the chain until it breaks, but to fracture through course grained metal, without reduction of area. In our experience this is a condition met with in the chain as purchased from the manufacturer, as is shown by the fact that failures are often experienced during the first day the chain is put into service, and some chains have to be removed from service after less than one month's time, owing to so large a number of links having failed and having been replaced by slightly larger sized split links made of heat treated alloy steel.

Our experience has been that when we get a chain which is a good chain, it remains good and does not cause failure for a long period of time. When a chain is bad, we have found it very difficult to treat it so as to completely rectify the trouble. Possibly closely following the method suggested by Mr. Merten of heating to about 1900 degrees Fahr. for an hour's time, cooling to a black heat, and then reheating to 1650 degrees Fahr. for an hour, followed by fairly rapid cooling might fully remove the course grain which causes the brittleness, but it might reduce the strength, leaving the chain so it would stretch too easily. Such heat

treatment on considerable lengths of chain should be carried out where control equipment and facilities are available. This makes it seem desirable for it to be done by the chain manufacturer.

If the chain manufacturer were to send out all chains in good structural condition by such treatment as proposed by Mr. Merten, it is the writer's opinion that there would be very little need for service annealing of such chains by the user.

J. F. HARPER: I thoroughly appreciate Mr. Merten's excellent paper in regard to the annealing of chain. His treatment is one which we have found to be excellent. There is just one question I would like to ask Mr. Merten, and that is if he has made any strength tests on his chain after this annealing treatment. We have found that there has been a considerable drop after annealing in the safe working load which is allowed by figures given by the manufacturers of chain. There is also a wide spread in the figures of the various manufacturers. If Mr. Merten has any information in regard to these safe working loads, other than those included in the recommended practice, and especially loads which can be used after this annealing treatment, I feel it would be a valuable contribution to the industry.

B. F. SHEPHERD: Mr. Merten, in the closure of his paper on crane chains, spoke of a feature which I think Mr. deForest was rather reluctant to discuss, and that is what constitutes a safe working load for a chain. The stresses on the chain are influenced by the angle which the chain is placed on the work, but the impact stresses which are more serious are the impact stresses caused by the operator. Quickly raising a heavy load from the ground or lowering a load and stopping it a few feet from the ground rather suddenly, causes the impact stresses which really do the greatest harm.

With regard to the annealing of the chain, we also went into that pretty carefully about five years ago and came to the conclusions Mr. Merten stated, that a chain was probably more likely to fail after annealing, i. e., after the customary annealing, than before. We substituted for the annealing of chain a periodical monthly inspection, all chains being very carefully numbered. That inspection has resulted very satisfactorily; we have had practically no failures of crane chains which were not directly traceable to some condition of operation. In this periodical monthly inspection we have had occasion to take out links which had developed some slight flaw, the weld started to open up or developed some defect which would probably have caused those chains to fail, anneal or no anneal.

Author's Reply to Discussion

Mr. deForest was kind enough to direct his discussion to me prior to this meeting, and I want to say that as far as the causes of failures are concerned, there is not any contention between himself or myself or any one of the investigators. However, my remedy is one in which we differ, and I have not any excuses to offer. I want to call attention to the fact that a chain usually fails after annealing rather than after initial

service, straining. It is the annealing at low temperatures that is getting the shop into trouble rather than the further use of the chain in the strain-hardened condition, and I am about ready to state that it is the annealing practice rather than the deterioration of the link that is responsible for most failures.

In Mr. Gough's paper there is mention made, and Mr. deForest points out, that there are indications of overheating a chain material when annealed at high temperatures. I take exception to the statement; neither at 2000 degrees nor 2100 nor 2200 degrees Fahr. can a steel or iron of low carbon content or, for that matter, a high carbon steel, if properly handled, be overheated or does it show any overheating and evidence of intercrystalline fusion, the significant term for overheating.

With regard to safe loading of a chain, the trouble is, what constitutes a safe load? Where should we draw the line When we lift with a chain, the load is rarely a straight one and we must consider compound stresses and in case of two or probably three crane chains hooked on to a large piece of work, the shop foreman or supervisory personnel of chain activities certainly are not the parties to leave the mathematical calculation of strain adjustment in a chain to, and it is for reasons of this kind that a chain should be periodically reannealed, and the grain structure re-adjusted and re-formed so that it again presents structural condition which can safely be put under a schedule of loading consistent with good chain material.

Mr. Frisbie's questions I will answer by referring to my previously published work on "High Temperature Annealing of Castings and Forgings."

With regard to answering Mr. Harper's question, we have made tests, but while after a high temperature anneal the elongation remained high the ultimate tensile strength was materially reduced, the second and third reheating as described brought it back to an even better condition than we obtained from a strain-hardened link, and while I have not the exact figures available, they were anywhere from 8 to 15 per cent higher.

Obviously there are two serious objections to high temperature work, one is the ordinary chain annealing furnace is not adapted to withstand temperatures around 2000 degrees Fahr. for any length of time. I have overcome this difficulty by glazing the furnace walls with a high voltage porcelain glaze called Albany slip; this glazing has resulted in preserving the refractory furnace lining and in considerable economies of heating. The second objection is heavy scaling and wastage of metal to which Mr. Lutts refers in his discussion. Experiments now in progress with suitable protective coatings of inert characteristics with respect to iron at the high temperature promise to eliminate this objection. The results will be the subject of a later paper on this subject.

Lt. Commander R. N. Wallins' remarks are particularly interesting and I fully agree with him that the chemistry of the chain material is of enormous importance in complete and satisfactory solution of the problem in which the neglect of attention to any one of the various aspects may result in injury and loss of life.

SURFACE COOLING OF STEELS IN QUENCHING

By H. J. French, G. S. Cook and T. E. Hamill

Abstract

A study was made of the surface cooling of steel spheres when quenched in water, sodium hydroxide solutions, oils or cooled in air. The characteristics of the cooling curves are described and the effects of some of the variables encountered in commercial heat treatment upon the cooling of steel bodies are discussed. These variables include mass, oxidation and smoothness of the surface, relation of the character of surface to the coolant, manner of circulation of the coolant and gases formed by or released from the coolant. Center and surface cooling curves obtained for pressure spray quenching with water are correlated with the tensile and impact properties obtained in low carbon steels, American ingot iron and wrought iron. Comparisons are also made between experimental cooling curves and cooling curves derived from two different sets of assumptions.

I. Introduction

In experiments previously reported[1, 2, 3] a study was made of the effects of mass in quenching and of some of the characteristics of cooling curves taken at the center of steel specimens of different sizes and shapes. Equations were derived by which it was possible to compute, with an accuracy sufficient for many practical purposes, the entire time-temperature cooling curves for

[1] H. J. French and O. Z. Klopsch: Quenching Diagrams for Carbon Steels in Relation to Some Quenching Media for Heat Treatment. Transactions, American Society for Steel Treating, Vol. 6, 1924, p. 251.

[2] H. J. French and O. Z. Klopsch: Initial Temperature and Mass Effects in Quenching. Bureau of Standards Technologic Paper 295; Transactions, American Society for Steel Treating, Vol. 9, 1926, p. 33.

[3] H. J. French and O. Z. Klopsch: Characteristics of Quenching Curves. Bureau of Standards Technologic Paper 313, 1926.

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A paper presented before the tenth annual convention of the society, held in Philadelphia, October 8 to 12, 1928. Of the authors, who are members of the society, H. J. French is senior metallurgist, G. S. Cook is associate physicist, and T. E. Hamill is laboratory assistant at the Bureau of Standards, Washington, D. C. Manuscript received July 5, 1928.

the center of various sizes of the simple shapes provided only certain coolant constants were known or first obtained.

Such studies of center cooling give useful information and when combined with a knowledge of the constitutional changes produced in steels by different coolants give a reasonably satisfactory working knowledge of the cooling properties of various liquids. However, they do not give a complete picture.

The loss of heat from metal bodies takes place through the surfaces in contact with the coolant. Measurements made at the center or other points in the interior may reasonably be expected to reflect the major changes which take place at the surface, but it is also probable that some important features of the surface cooling are masked at interior points.

Practically no experimental determinations have been reported of the surface cooling of steel samples immersed in the oils, water, and aqueous solutions which are widely used in commercial heat treatment, and there are few experimental surface cooling curves available of samples cooled in air. Until additional information is obtained, many questions relating to quenching and quenching media will remain unanswered.

The importance of the subject of surface cooling will be realized when it is recalled that the object of the quenching of steels is frequently the hardening of only the surface areas and not the complete hardening of the entire mass of metal.

Practical experience emphasizes the need for more information on the occurrences at the contact surfaces between the metal and the coolant (or their products). Cases have been encountered where failure of the steel to harden in an accustomed manner has been remedied by a change in the conditions of operation of the heating furnace so as to bring the oxidation of the metal surface under better control. Cracking of steel parts during or after quenching introduces the subject of internal stresses. Consideration of internal stresses presupposes a knowledge of the temperature distribution during quenching and this, in turn, requires that the cooling at the surface be known.

Theoretically derived cooling curves for drastic (rapid) coolants such as water generally involve the assumption of instantaneous surface cooling from the initial (quenching) temperature to the final (coolant) temperature, but this assumption can be

only a rough approximation to the true conditions since there are coolants which are more "drastic" than water.

This all points to the need for additional information on surface cooling when steel bodies are immersed in the different liquids used in practical heat treatment and constitute the principal reasons for undertaking the experiments which are to be described. The tests made relate primarily to the surface cooling of spheres in air, oils, water and caustic soda solutions, but some data on center cooling have been included for purposes of comparison.

II. Equipment and General Procedure Employed

The equipment and general procedure employed in studying surface cooling of steel bodies were the same as those used in the study of center cooling which have already been described in detail.[4]

Steel specimens of selected dimensions were heated to the desired temperatures in electric resistance furnaces, and then introduced into the coolant under conditions which will subsequently be described. A thermocouple was attached to the test specimen in a manner which will also be described later and time-temperature cooling curves obtained by projecting the image of the "string" in a "string galvanometer" on a moving photographic paper within a suitable camera. A photograph of the assembled equipment for these tests is shown in Fig. 1.

The spheres used in the experiments were made from steels having the chemical compositions shown in Table I. The variations in the compositions of the different sizes are considered unimportant since no quantitative evaluation of the effects of size was attempted.

Unless otherwise stated, the heat of transformations found at temperatures below about 300 degrees Cent. (570 degrees Fahr.) have been disregarded in plotting smooth curves since this simplifies comparisons. This was not done for air cooling where large heat effects were observed at relatively high temperatures as shown in the various charts.

Prepared oil No. 2, used in most of the experiments, was the same as that used in previous studies of center cooling. Its gen-

[4] See footnote 1.

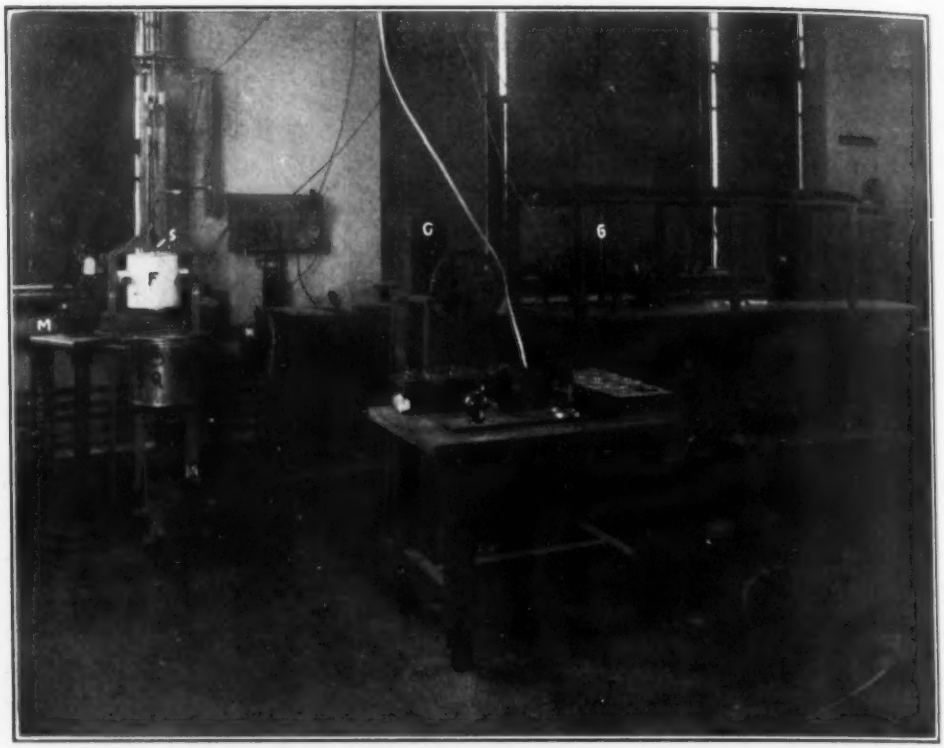


Fig. 1—Photograph Showing Assembled Equipment Used in the Tests. F = Furnace for Heating Small Specimens; Q = Bath for Quenching Small Specimens; S = Specimen; M = Motors for Rotating the Quenching Tank or Stirring Coolant; C = Camera for Recording Results; G = String Galvanometer.

eral properties are given in a previous publication.[5]

Unless otherwise indicated, the thermocouple for determining surface temperatures was located near the bottom of the spheres.

III. Preliminary Experiments Relating to Test Methods

The problem of securing consistent and reproducible cooling curves at the *center* of steel bodies is not simple and for this reason a statistical study was made of numerous experiments with specimens of different sizes and shapes, as has already been reported.[6] The difficulties increased appreciably when attempting to study the *surface* cooling.

The transfer of heat from the metal to the coolant takes place at the surface of the solid body. Therefore, the observed surface cooling is directly affected by momentary and localized changes

[5]See footnote 1.

[6]See footnote 2.

Table I

Steels from which the Spheres were Prepared

Spheres, Diameters, inches	Chemical Composition, per cent[1]					
	C	Mn	P	S	Cr	
			Less than			Remarks
½ to 2½ incl.	1.00 to 1.15	0.20 to 0.50	0.035	0.035	1.25 to 1.75	Bearing steel
4¾ to 7½ incl.	0.60 to 0.80	0.90 to 1.20	0.05	0.05		Forging steel
11 and above	0.19					Forging steel

[1]Individual spheres were analyzed and the results were within the commercial limits set by the suppliers as given in the table.

in conditions. These variations may be "smoothed out" or masked before they are transmitted to the center.

A second difficulty arises from the rapid rates of temperature change which, in certain portions of the cooling range, may reach or exceed several thousand degrees Centigrade per second in pieces 4 inches or more in diameter. Such rates of temperature change are not difficult to record with fair accuracy but a localized change in conditions, which endures for only a fraction of a second, may change the form, and shift the greater part, of the cooling curve and so give different results for supposedly similar quenching conditions. Hence, the selection of a method of test is, in itself, an important problem.

Few methods of measurement can be adapted readily to the study of the rapid temperature changes encountered in the quenching of steels. Those most easily applied include the use of thermocouples for measuring temperatures. Both the method of attachment to the surface and the location on the test specimen may be conceived to exert a pronounced influence upon the cooling curves obtained and perhaps, also, materially affect the manner of cooling in the area where measurements are made. For these reasons attention was first given to the method of attaching the thermocouple to the test specimen.

1. Method of Attaching the Thermocouple to the Specimen

There is no method which can be readily applied which can be said to give more than an approximate determination of surface temperatures during the quenching of steels. The attachment of thermocouples to the surface of the test specimen by any practicable method, disturbs the continuity of the surface or the underlying metal and modifies to some degree at least the conditions

which can be conceived to exist in an undisturbed surface. There is, therefore, no base-line of comparison and it becomes necessary to compare the different methods of attachment of the thermocouple amongst themselves. Such comparisons will not necessarily prove that one method gives a closer approximation to true conditions than another but should indicate which are the most promising methods.

The several methods used for attaching the thermocouple to the specimen in the preliminary tests may be grouped under two main headings, namely, (1) passage through the body of the test

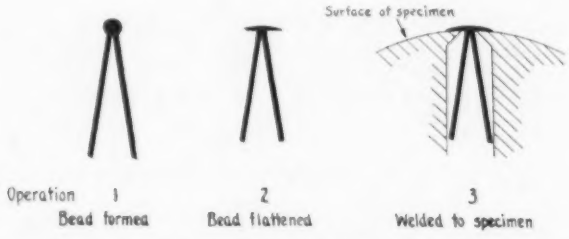


Fig. 2—Sketch Showing Method of Attachment of Thermocouple to Specimen—Method No. I.

specimen to the surface, and (2) attachment directly to the surface from outside the specimen. In all cases, the thermocouple was attached to the surface by welding.

Method No. 1. In method No. 1, the thermocouple was first made by forming a bead on the ends of chromel-alumel wires, and the bead was then flattened. The wires were passed through a hole in the specimen and the bead welded to the steel surface over the hole, as is illustrated in Fig. 2.

Method No. 2. In this method the thermocouple wires were flattened on the ends, passed through a hole in the test specimen, laid flat on the surface, as shown in Fig. 3, and welded individually to the steel. The hole was then packed with asbestos wool or other insulating material.

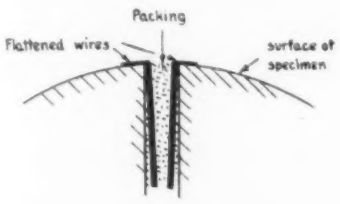
Method No. 3. In this method beads were formed separately on the ends of each thermocouple wire. The wires were passed through individual holes in the specimen, and the beads, previously flattened, were welded over the holes to the steel surface, as shown in Fig. 4.

Method No. 4. In the method illustrated in Fig. 5, the thermo-

couple wires were laid individually on the surface, from outside the test specimen, and welded to the steel.

Method No. 5. A bead was first formed on each of the thermocouple wires, flattened on the end and welded to the surface of the steel specimen. The excess metal was filed off subsequent to welding as is illustrated in Fig. 6.

The procedure used in welding thermocouples to the surface was as follows: A bead was made on the end of each wire by melting in an oxy-gas flame, using borax as a flux. These beads were filed flat on the ends and the wires were cleaned a short distance from the beads. Each one was then clamped between two copper blocks, one of which was connected to the secondary of a step-down transformer (the other terminal of the secondary was connected to the vise in which the specimen was held). The end of the bead was held firmly against a freshly filed spot on the specimen while the current was made in the primary for a short time by means of a key. The voltage applied to the primary of the transformer was regulated to suit the size of wires being welded, higher voltage being required for larger wires. The best results were had without the use of any flux.



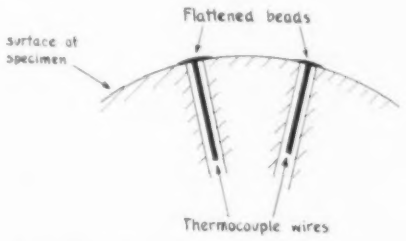


Fig. 3—Sketch Showing Method of Attachment of Thermocouple to Specimen—Method No. II. Fig. 4—Sketch Showing Method of Attachment of Thermocouple to Specimen—Method No. III

Methods 2, 3, 4 and 5 are alike in one respect. The area of the steel surface over which temperature measurements are to be made is not in contact with the coolant but is covered by a layer of the thermocouple materials. Even if this layer is thin, the temperature of the surface of the steel will presumably lag behind the temperatures of a surface in direct contact with the coolant.

One of the main objects of passing the thermocouple through holes to the surface was to eliminate projections and approach the contour of an undisturbed surface. However, methods 1, 2, and

3 are open to the objection that the spot over which the temperature is measured is not backed up by metal as is the surface of a specimen without holes. This should be most important with method 1, in which the thermal junction between the chromel and

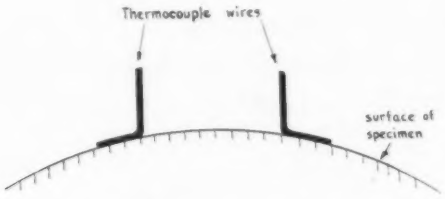


Fig. 5—Sketch Showing Method of Attachment of Thermocouple to Specimen—Method No. IV.

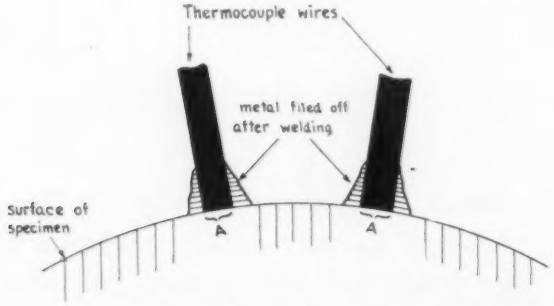


Fig. 6—Sketch Showng Method of Attachment of Thermocouple to Specimen—Method No. V.

alumel wires is directly over the hole. Futhermore, there is no ready means of determining whether this thermal junction is near or well below the steel surface.

In method 2 the hole is not sealed by metal and there was generally leakage of the coolant into the packing.

Methods 4 and 5 have the disadvantage that they introduce projections from the surface of the specimen. These will tend to entrap gas and may retard the cooling. Likewise, the thermocouple leads are in contact with the coolant. Difficulties may arise from this in two ways, by conduction through the coolant and by the development of an e.m.f. between the leads. Electrical conduction would tend to increase the observed speeds of cooling and counteract any retardation associated with entrapped gas. However, such increases would probably be small due to the small size of the thermocouple wires used. The effects of any e.m.f. developed can probably also be neglected in the experiments under

discussion as is shown by the following experiment. A specimen was prepared in the usual manner except that the thermocouple leads extended several inches below the sphere so that they protruded from the furnace. When these leads were immersed in 5 per cent sodium hydroxide, the e.m.f. indicated by a potentio-

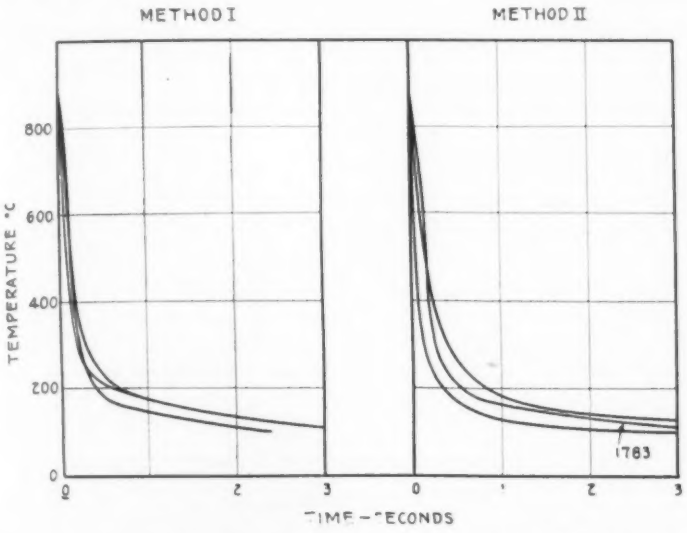


Fig. 7—Surface Cooling Curves Obtained with Methods I and II in Water Quenching. 1-Inch Spheres Quenched Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at 3 Feet Per Second. Each Curve, Except Test No. 1783, is the Average of Two or More Tests.

meter was not affected appreciably. This gave much longer lengths of leads in contact with the coolant than obtained in the quenching experiments and would have increased such effects if they existed.

Figs. 7, 8 and 9 show surface cooling curves for 1-inch spheres quenched into water at 20 from 875 degrees Cent. (65 from 1605 degrees Fahr.) when using each of the five methods for attaching the thermocouple to the specimen. The most consistent results were obtained in repeated experiments with method 5. Fair consistency is shown in Fig. 7 for method 1, but much wider variations were encountered with this method in experiments with larger spheres. Method 4 gave fairly consistent results, the greatest variations being observed at the low temperatures. Erratic results were obtained with method 3.

Method 5 which gave the most consistent results is the one in which it should be least troublesome to reproduce the construction

of the thermocouple mounting. The area of contact is the cross-sectional area of the wire and can be made very nearly the same each time. If the weld does not extend over the entire contact surface breakage usually results, if not while filing away excess metal, upon quenching.

As has been mentioned previously these five methods of measuring temperatures during quenching should all give a lag which

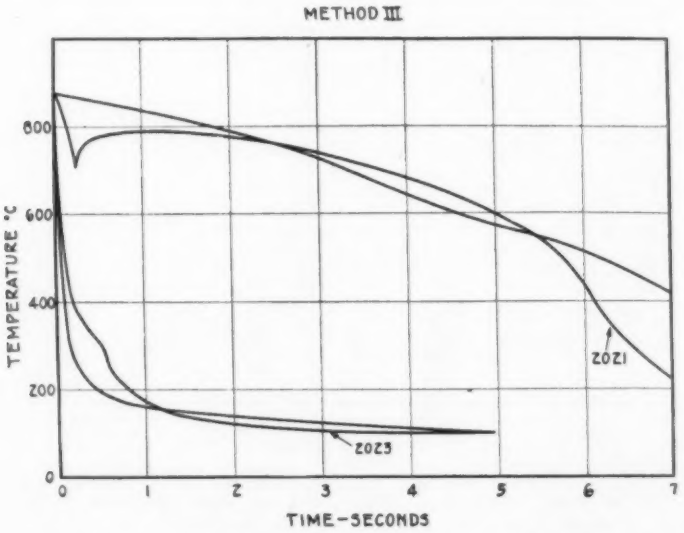


Fig. 8—Surface Cooling Curves Observed with Method III in Water Quenching. 1-Inch Spheres Quenched Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at 3 Feet Per Second. The Curves Without Test Numbers Are Averages of Two or More Tests.

should be a maximum during the early part of the quench where the temperature gradients are largest. It seems reasonable to assume that this lag is least in cases where the initial drop in indicated temperature is most abrupt. One of the curves taken by method 3 shows a somewhat more rapid temperature drop than any of the others. However, method 5 consistently gave the most rapid initial drop in temperature of any of the methods, but when comparisons were made between the most rapid cooling curves obtained by each method the results were found to be nearly the same.

The differences encountered with different methods of attaching the thermocouple to the test specimen are reduced with slower cooling rates, as in air. Methods 4 and 5 gave practically the same air cooling curves. The cooling observed with method 2

was slow in air, just as it was relatively slow in water (Fig. 10).

Based on these experiments it seemed logical to select method 5 for rapid coolants since the lag introduced by this method of at-

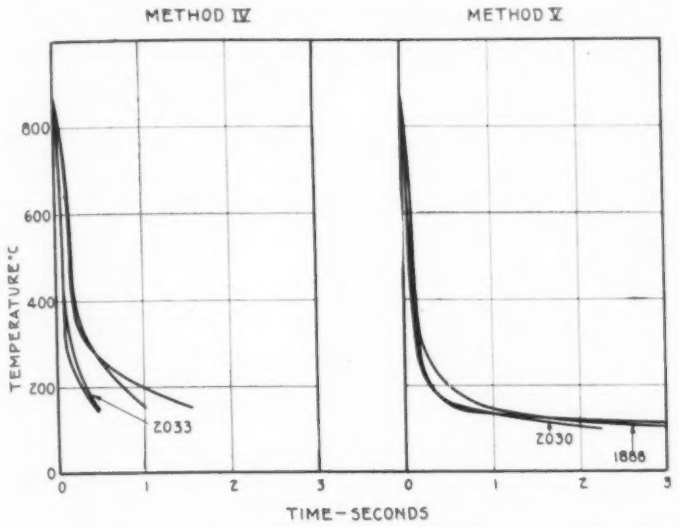


Fig. 9—Surface Cooling Curves Observed with Methods IV and V in Water Quenching. 1-Inch Spheres Quenched Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at 3 Feet Per Second. The Curves Without Test Numbers Are Averages of Two or More Tests.

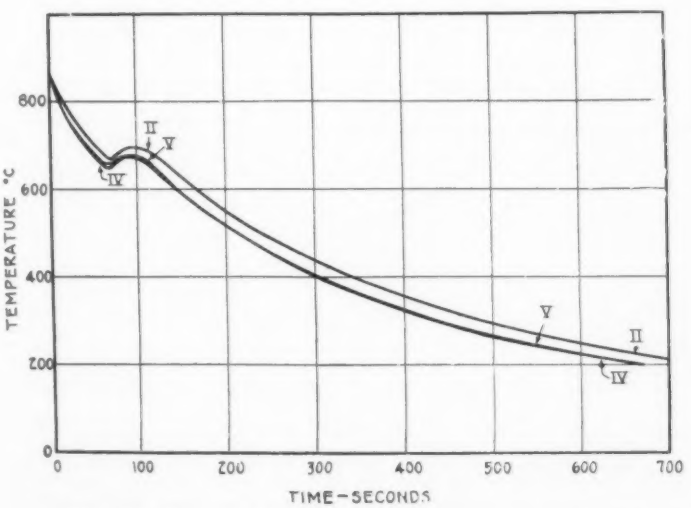


Fig. 10—Surface Cooling Curves Obtained in Still Air With Methods II, IV and V. Each Curve is the Average of Two Tests.

taching the thermocouple to the surface was as small as with any of the other methods. Furthermore, it was easiest to reproduce the construction of the thermocouple in this method. With slow cool-

ing, as in air, methods 4 or 5 may be used since they gave practically the same cooling curves.

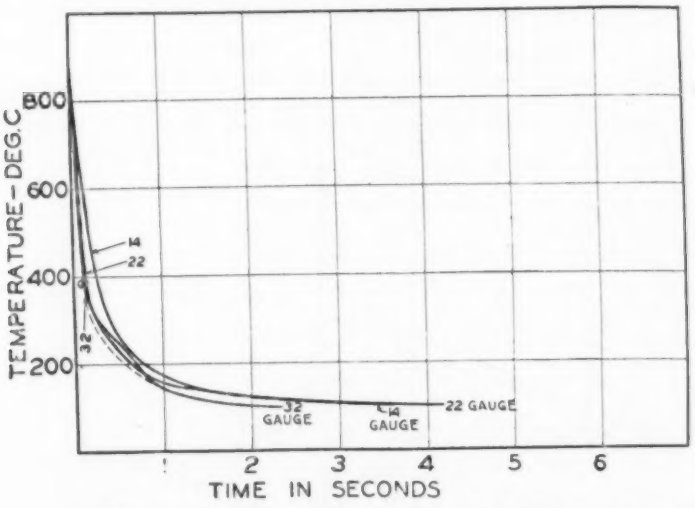


Fig. 11—Surface Cooling Curves Obtained With Thermocouples of Different Sizes When Quenching Into Water. The Thermocouple was Attached to the Specimen by Method V. Each Curve is the Average of Two or Three Tests on a 1-Inch Sphere Quenched Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at 3 Feet Per Second.

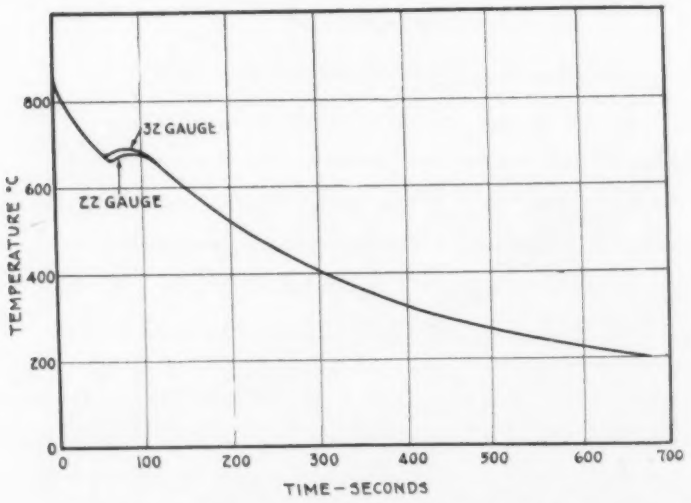


Fig. 12—Surface Cooling Curves Obtained with Thermocouples of Different Sizes When Cooling in Still Air. The Thermocouple was Attached to the Specimen by Method IV. Each Curve is the Average of Two Tests.

2. *Size of Thermocouple*

The experiments described clearly indicate that the method of attaching the thermocouple to the surface may affect the observed

cooling appreciably. It is probable that the observations are also affected by the size of the thermocouple wire.

Cooling curves taken in water with method 5 using 14, 22 and 32 B. and S. gage thermocouples are shown in Fig. 11. Air cooling curves obtained by method 4 using 22 and 32 gage thermocouples are shown in Fig. 12.

The effect of thermocouple size upon the recorded times for the surface of a sphere to reach different temperatures when

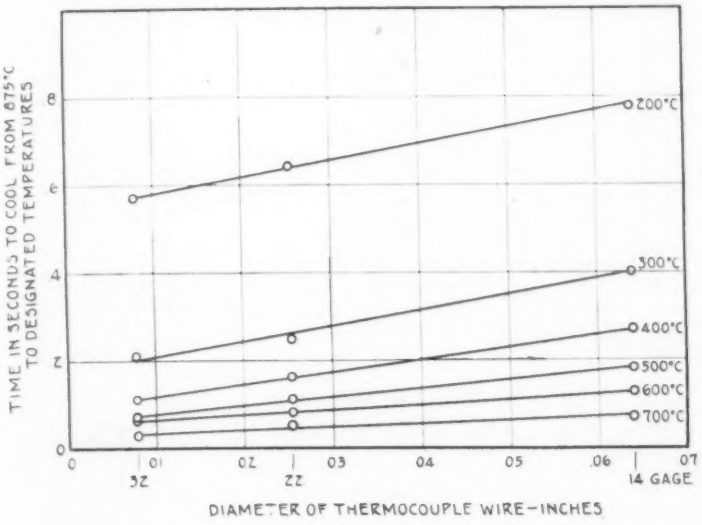


Fig. 13—Effect of Thermocouple Size on the Observed Time of Cooling from 875 Degrees Cent. (1605 Degrees Fahr.) to the Designated Temperatures When Quenching Into Water. 1-Inch Sphere Quenched Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at 3 Feet Per Second. Based on Data Given in Fig. 11.

quenched from 875 degrees Cent. (1605 degrees Fahr.) into water is shown in Fig. 13. These times decrease generally with decrease in size of the thermocouple and within the limits of the experiments (size of thermocouple and errors), appear to be a linear function of the diameter of the thermocouple wire.

It will also be observed from Fig. 13 that the decrease in cooling time with decrease in size of thermocouple is greater for the large cooling ranges 875 to 200 or 300 degrees Cent. (1605 to 390 or 570 degrees Fahr.) than for the small cooling intervals 875 to 600 or 700 degrees Cent. (1605 to 1110 or 1290 degrees Fahr.).

Fig. 13 suggests the possibility of extrapolating the results to wires of zero diameter but this is hardly justified without extending observations to wires of much smaller diameter than 32 B

and S gage. While decrease in thermocouple size should give a closer approximation to surface temperatures, practical difficulties were encountered in handling 32-gage thermocouples, and it was considered that the use of 22-gage wire would meet the requirements of the tests in view. In considering this selection, it should be kept in mind that there are many variables associated with the

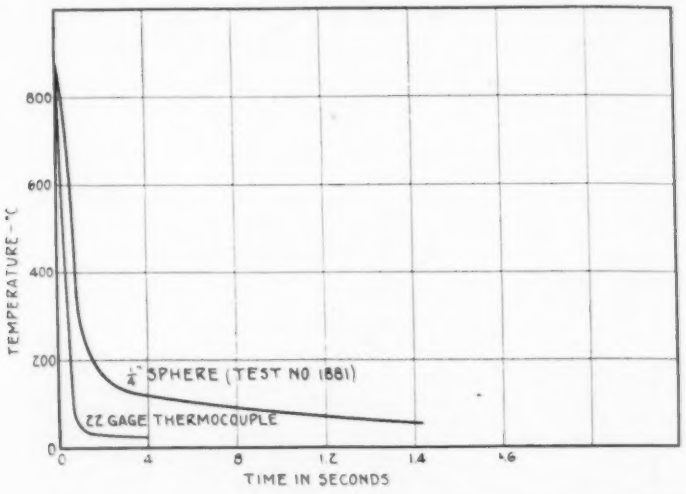


Fig. 14—Comparison of Cooling Curves for a 22 Gage Thermocouple and for the Surface of a ¼-Inch Sphere Both Quenched Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at 3 Feet Per Second. Note That These Curves Are Plotted to an Expanded Time Scale.

quenching process which are difficult to control and which may produce differences much larger than those resulting from a change in thermocouple size. This will become evident in subsequent sections of the report.

Comparison of Figs. 11 and 12 shows that the thermocouple size is less important in air cooling than in rapid cooling in water. Therefore, it is probable that the variations encountered in water quenching a 1-inch sphere (shown in Fig. 11) are larger than those which would be observed in water quenching larger spheres.

3. Response of Galvanometer Equipment

The rates of temperature change observed in the foregoing experiments were very high in portions of the cooling range. The question arises whether these rapid changes are so close to the limits of response of the thermocouple and string galvanometer equipment as to affect the observed results. A 22-gage chromel-

Table II

Time Required for the Surface of Steel Spheres of Different Sizes to Cool to Different Temperatures when Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) in 5 Per Cent NaOH at 20 Degrees Cent. Moving at 3 Feet per second[1]

Size, inches	Test Number	Time in Seconds to Cool to 700°C	600°C	500°C	400°C	300°C	250°C	200°C	150°C
¼	1901	.025	.030	.033	.040	.06	.10	.21	1.05
	1902	.025	.040	.050	.063	.12	.23	.42	.67
	1903	.030	.040	.045	.050	.09	.13	.23	.36
Average		.027	.037	.043	.051	.09	.15	.29	.69
½	1904	.035	.040	.050	.055	.07	.11	.15	.43
	1905	.035	.038	.046	.060	.09	.13	.22	.49
	1945	.032	.050	.073	.090	.11	.14	.32	.92
	1949	.016	.043	.060	.085	.17	.24	.35	.65
	1950	.020	.040	.060	.077	.10	.15	.26	.53
Average		.028	.042	.058	.073	.11	.15	.26	.60
1	1896	.035	.040	.045	.060	.08	.10	.15	.40
	1897	.050	.060	.080	.085	.11	.19	.40	1.20
	1947	.028	.040	.045	.064	.14	.21	.34	.71
	1948	.020	.030	.050	.086	.19	.32	.52	.99
Average		.033	.042	.055	.074	.13	.21	.35	.82
2½	1899	.025	.040	.060	.065	.08	.10	.29	.65
	1900	.020	.030	.040	.050	.07	.13	.25	.80
	1951	.030	.043	.070	.100	.15	.20	.31	.52
	1952	.020	.040	.075	.120	.19	.23	.35	.84
	1953	.020	.043	.080	.130	.21	.28	.39	.66
Average		.023	.039	.065	.093	.14	.19	.32	.69
4¾	1981	.040	.070	.11	.13	.15	.17	.28	1.60
	1982	.050	.065	.08	.12	.19	.24	.35	1.10
	1983	.040	.062	.09	.12	.18	.23	.32	.78
	1984	.042	.065	.08	.11	.15	.18	.22	.31
Average		.043	.066	.09	.12	.17	.21	.29	.95
7.15	1985	.030	.060	.10	.13	.22	.34	.47	1.90
	1986	.050	.090	.12	.16	.27	.33	.44	.94
	1987	.040	.060	.09	.12	.24	.27	.35	.60
Average		.040	.070	.10	.14	.24	.31	.42	1.15
11¼	1988	.055	.12	.18	.32	.60	.98	1.51	2.66
	1990	.030	.11	.21	.33	.54	.73	1.04	1.70
Average		.043	.12	.19	.33	.57	.86	1.28	2.18

[1]Heat effects of transformations disregarded.

alumel thermocouple (without a steel specimen) was quenched in water at 20 degrees Cent. (65 degrees Fahr.), to throw light on this question. The couple was made by welding the ends of the two wires together and filing away excess metal at the junction until the bead was reduced approximately to the diameter of one wire.

Fig. 14 shows that the cooling observed on the thermocouple alone was much faster than that observed on any specimen. Thus, the equipment is capable of recording higher rates of temperature change than those encountered with any of the spheres tested. The

Table III

Time Required for the Surface of Steel Spheres of Different Sizes to Cool to Different Temperatures when Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) in Water at 20 Degrees Cent. Moving at 3 Feet per Second[1]

Size, inches	Test Number	Time in Seconds to Cool to 700°C	600°C	500°C	400°C	350°C	300°C	250°C	200°C	150°C
¼	1881	.05	.06	.07	.08	.09	.10	.12	.16	.23
	1885	.05	.06	.07	.11	.13	.16	.19	.23	.30
Average		.05	.06	.07	.10	.11	.13	.16	.20	.27
½	1827	.07	.10	.11	.13	.14	.14	.19	.31	.65
	1828	.03	.07	.12	.18	.21	.25	.32	.43	.58
	1890	.09	.10	.11	.13	.13	.17	.28	.65	..
Average		.06	.09	.11	.15	.16	.19	.26	.46	.62
1	1823	.06	.10	.12	.15	.17	.22	.34	.58	1.08
	1824	.05	.06	.08	.12	.15	.19	.28	.43	.85
	1888	.06	.07	.07	.08	.11	.14	.19	.27	.55
Average		.06	.08	.09	.12	.14	.18	.27	.43	.83
2½	1819	.04	.08	.16	.31	.50	.77	1.18	1.82	2.80
	1820	.03	.05	.08	.10	.13	.17	.27	.42	.68
	1821	.02	.03	.05	.07	.10	.13	.17	.32	.80
	1854	.04	.07	.10	.18	.30	.50	.77	1.23	2.26
	1856	.02	.03	.05	.10	.13	.16	.26	.47	.88
Average		.03	.05	.09	.15	.23	.35	.53	.85	1.48
4¾	1873	.05	.06	.13	.20	.29	.44	.66	1.11	3.10
	1874	.07	10	.16	.23	.28	.34	.56	1.20	5.00
Average		.06	.08	.15	.22	.29	.39	.51	1.16	4.05
7½	1864	.11	.22	.39	.60	.75	.95	1.28	2.01	3.75
	1869	.07	.12	.17	.25	.30	.60	.92	4.75	...
	1872	.07	.12	.17	.25	.30	.60	.97	1.72	3.40
	1875	.08	.18	.33	.65	1.08	1.90	3.10	5.00	8.40
	1876	.08	.18	.30	.50	.75	1.30	2.20	5.00	...
Average		.08	.16	.27	.45	.64	1.07	1.69	3.70	5.18
11¼	1877	.10	.28	.57	1.23	2.03	6.10	9.50	17.5	26.4
	1880	.10	.15	.25	.40	.70	3.40	10.0	22.0	...
Average		.10	.22	.41	.82	1.37	4.75	9.75	19.8	26.4

[1]Heat effects of transformations disregarded.

recorded cooling of the thermocouple is quite different from that of a similar couple attached to the surface of a steel sphere. Therefore, the results for the spheres cannot properly be considered to represent merely the cooling of a thermocouple suspended from a metal sample. They approach the cooling at the surface of the steel specimens.

The response of the galvanometer is another factor which imposes a limit on the cooling rates which can be determined. In the case of the described equipment, this limit is well above the rates of temperature change which must be measured. As the galvanometer was used, it had a period of about 0.01 seconds, short circuited, and it was not critically damped. It was therefore,

Table IV

Time Required for the Surface of Steel Spheres of Different Sizes to Cool to Different Temperatures when Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) in No. 2 Oil at 20 Degrees Cent. Moving at 3 Feet per Second[1]

Size Inches	Test Number	Time in Seconds to Cool to 800°C	700°C	600°C	500°C	400°C	300°C	250°C	200°C
¾	1886	.03	.14	.37	.76	1.27	2.28	3.00	4.10
	1887	.03	.14	.32	.62	1.18	2.40	3.15	4.30
	1915	.03	.14	.32	.65	1.45	2.68	3.55	4.70
	1916	.03	.14	.35	.82	1.62	2.75	3.65	5.10
Average		.03	.14	.34	.71	1.38	2.53	3.34	4.60
1½	1867	.04	.13	.30	.90	2.03	3.95	5.56	7.9
	1868	.04	.13	.35	1.00	2.18	4.05	5.60	8.2
Average		.04	.13	.33	.95	2.11	4.00	5.58	8.1
2	1878	.03	.12	.30	.80	2.60	7.0	11.5	19.5
	1879	.04	.15	.32	1.15	4.45	9.9	13.0	20.2
	1919	.04	.18	.55	1.75	3.50	8.0	14.0	22.6
Average		.04	.15	.39	1.23	3.52	8.3	12.8	20.8
2½	1871	.08	.26	1.10	4.0	9.3	52	86	133
	1923	.05	.25	1.10	3.2	9.2	63	98	144
	1924	.06	.20	1.50	4.8	11.2	63	101	143
	1926	.03	.15	.80	2.7	7.5	24	70	116
	1927	.05	.15	.60	2.5	7.0	24	45	90
Average		.05	.20	1.02	3.4	8.8	45	80	125
4¾	1890	.12	.31	1.5	7.6	50	203	277	367
	1894	.04	..	3.5	13.3	72	179	248	312
	1895	.04	.30	1.8	7.0	67	177	244	324
	1910	.03	.20	.6	9.0	73	179	256	335
	1979	.09	.42	3.9	32.0	103	227	285	375
Average		.06	.31	2.4	14.3	73	193	262	343
7½	1976	.06	.20	1.4	50	145	363	560	775
	1977	.11	.36	2.4	24	130	370	550	750
Average		.09	.28	1.9	37	138	366	555	768

[1]Heat effects of transformations disregarded.

unnecessary to attempt any correction for lag in the galvanometer as such corrections would have been beyond the accuracy of the observations.

IV. Effect of Size on Surface Cooling of Spheres

Cooling curves were taken on spheres of different sizes with the twofold purpose of studying mass effects and securing a more complete conception of the usefulness of the selected methods of determining the surface temperatures.

Summaries of the results obtained at the surface of spheres cooled in water, 5 per cent sodium hydroxide, an oil or air are given in Tables II to V inclusive. Several experiments were made for each size in each of the coolants and subsequent com-

Table V

Time Required for the Surface of Steel Spheres of Different Sizes to Cool to Different Temperatures when Cooled from 875 Degrees Cent. (1605 Degrees Fahr.) in Still Air at Room Temperature[1]

Size, inches	Test Number	Time in Seconds to Cool to 800°C	700°C	600°C	500°C	400°C	300°C	200°C
½	1656	7	23	51	93	148	227	396
	1718	7	23	46	85	133	203	360
Average		7	23	49	89	141	215	378
1	2008	12	42	100	190	307	452	695
	2009	12	46	107	197	307	444	685
Average		12	44	104	194	307	448	690
2½	1649	32	116	290	590	995	1540	2650
	1720	40	137	320	635	1095	1585	2415
	1736	37	135	315	605	985	1500	2500
	1740	35	122	307	595	945	1430	2230
Average		36	128	308	606	1005	1514	2449
4¾	1651	50	225	535	1125	1950	2830	4700
	1745	50	225	510	1035	1835	2890	4700
Average		50	225	523	1080	1893	2860	4700
7½	1754	70	360	1020	2120	3520	5140	8200
	1755	70	360	980	2060	3460	5230	8320
Average		70	360	1000	2090	3490	5185	8260
11¼	1743	75	600	1740	3240	5040	7440	12000
	1749	75	660	1860	3360	5040	7620	12360
Average		75	630	1800	3300	5040	7530	12180

[1]Heat effects of transformations disregarded.

ments relate largely to the average values. However, these should be used only for general comparisons since in many cases, there are appreciable variations in the individual results. Furthermore, the quenching conditions were not exactly the same for all of the spheres. Sizes up to and including 2½ inches in diameter were quenched with the equipment illustrated in Fig. 1, in which the motion of the coolant was produced by the rotation of the container; spheres of larger diameters were heated in larger furnaces and quenched in liquids in stationary tanks. In these cases, flow of the coolant past the specimen was obtained by moving the specimen by hand in the bath.

These two methods produced similar but by no means identical conditions at the surfaces of the spheres. Differences probably also existed in the quenching of the small spheres (¼ inch to 2½ inches in diameter) even though all these were handled with the one equipment. With a given velocity of coolant, the flow around a sphere ¼ inch in diameter will differ from that around a sphere of much larger diameter.

Also the disturbances momentarily produced by the introduction of the specimen into the bath would be a function of the size,

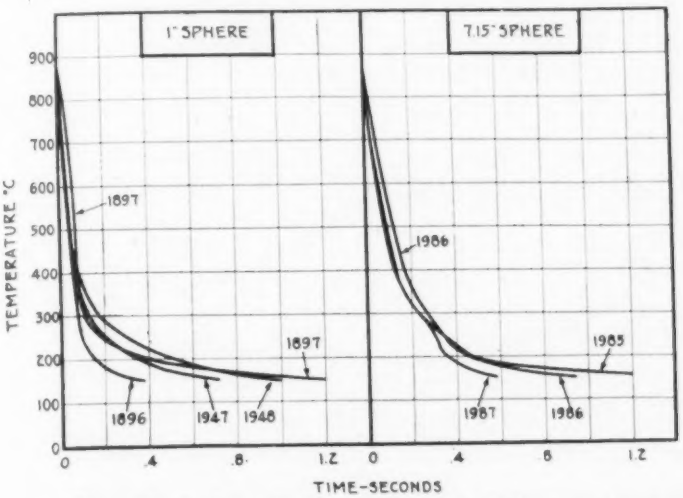


Fig. 15—Surface Cooling Curves of Spheres of Different Diameters Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into 5 Per Cent Sodium Hydroxide at 19 to 22 Degrees Cent. (65 to 70 Degrees Fahr.). Coolant Motion Approximately 3 Feet Per Second. Test Numbers Are Given in the Body of the Chart.

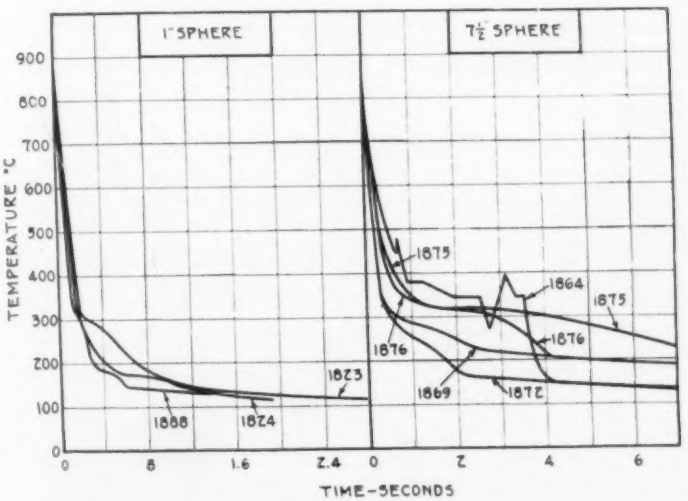


Fig. 16—Surface Cooling Curves of Spheres of Different Diameters Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water at 20 Degrees Cent. (65 Degrees Fahr.). Coolant Motion Approximately 3 Feet Per Second. Test Numbers Are Given in the Body of the Chart.

the character of the surface and the manner of introduction.[7] Variations in these factors can be expected to modify at least the

[7] G. E. Bell: On the Impact of a Solid Sphere with a Fluid Surface and the Influence of Surface Tension, Surface Layers, and Viscosity on the Phenomenon. *Philosophical Magazine*, 6 Series, Vol. 48, 1924, p. 753.

initial stages of cooling at the surface of the metal and indicate that difficulties would be encountered in securing exactly com-

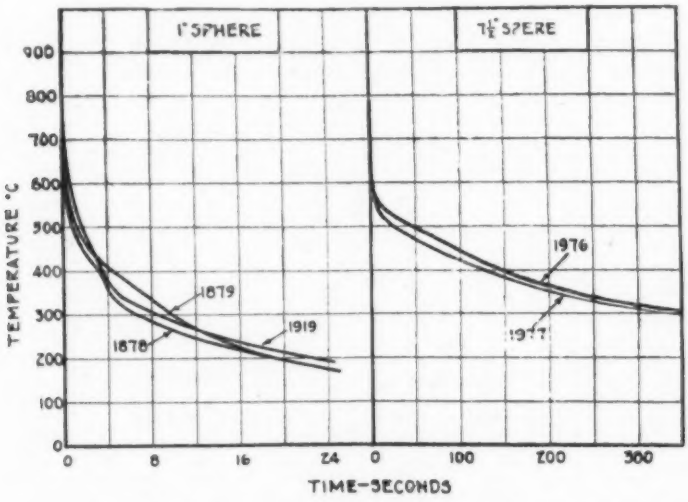


Fig. 17—Surface Cooling Curves of Spheres of Different Diameters Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into No. 2 Oil at 20 Degrees Cent. (65 Degrees Fahr.). Coolant Motion Approximately 3 Feet Per Second. Test Numbers Are Given in the Body of the Chart.

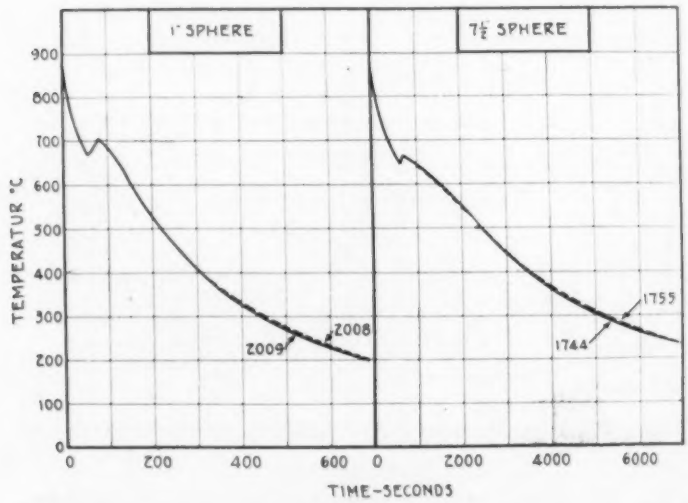


Fig. 18—Surface Cooling Curves of Spheres of Different Diameters Cooled from 875 Degrees Cent. (1605 Degrees Fahr.) in Still Air at Atmospheric Temperatures. 32 B & S Gage Thermocouple Attached to Specimens by Method IV. Test Numbers Given in the Body of the Chart.

parable quenching conditions for a wide range of sizes. However, the conditions of the experiments represented those which would be encountered in good commercial heat treatment and at least

should show the direction and order of magnitude of effects of changing size.

Representative cooling curves taken at the surface of spheres of different sizes quenched in the different media are shown in Figs. 15 to 18 inclusive, but a complete set of curves may be prepared from the data given in Tables II to V inclusive. In Figs. 15 to 18 inclusive, the curves for each size are plotted together to give some idea of the consistency of the results.

1. *General characteristics of the surface cooling curves*

In general, repetition of the experiments gave cooling curves which were similar for the first and last portions of the cooling range. At intermediate temperatures, around 300 to 500 degrees Cent. (570 to 930 degrees Fahr.), rather wide differences were sometimes observed. The magnitude of these variations and the intervals of both time and temperature over which they occurred increased with the diameter of the spheres. The curves also lost their smoothness in this range and showed many small fluctuations as illustrated in Fig. 19. These fluctuations indicate an unstable condition at the areas at which the thermocouple leads were attached to the test specimen.

In replotting the cooling curves no effort was made to reproduce all the small irregularities which were observed in the photographic records (Fig. 19) since the method of recording temperatures has limitations, already discussed, which would tend to smooth out such rapid fluctuations in temperature. It is probable that the temperature of any point on the surface fluctuates over wider ranges than those shown in Fig. 19, particularly at intermediate portions of the cooling range.

These effects indicate that different points on the surface behave in different ways at least until the average temperature of the entire surface approaches the boiling point of the coolant. The fact that all the curves for any one size of sphere became nearly the same as the temperature approached the boiling point of the coolant indicates that the fluctuations and unusually high temperatures at given times reflect localized conditions. They do not necessarily indicate what happens to the surface as a whole.

In quenching large specimens in water, spots were observed

to remain at "red heat" for several seconds after the steel was introduced into the coolant. This further substantiates the view that there are even more radical variations from average temperatures than are shown by any of the records obtained.

Since these small fluctuations were observed only throughout a portion of the cooling range and in some cases were almost

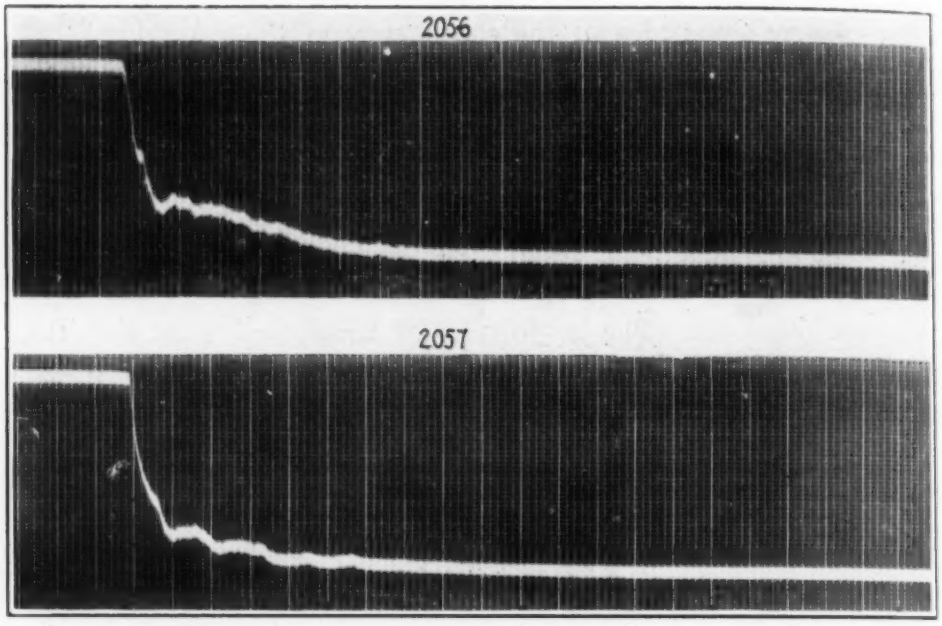


Fig. 19—Photographic Records of Surface Cooling of a 2½-Inch Sphere Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at 3 Feet Per Second. Test 2056 Represents the First Quench; Test 2057 Represents the Quench After Reheating the Same Sample and Thermocouple.

wholly absent, they cannot justly be ascribed to electrical effects due to the action of the coolant on the thermocouple leads. Furthermore, the fluctuations were less marked, and when present, were usually restricted to smaller temperature ranges, when quenching in caustic soda with good electrical conductivity and in oil with poor conductivity than when quenching in water.

The conclusion to be drawn from the described effects is that the cooling at the surface of steel bodies immersed in liquids moving at low velocities, as in the experiments, is seldom uniform from point to point. Evidence has also been obtained that the cooling at any particular point is not continuous but is the resultant of a large number of rapid temperature fluctuations throughout a part of the cooling range. These fluctuations were more

marked when quenching in water and 5 per cent sodium hydroxide than when quenching in oil.

There is a possibility that the heat of transformations of the

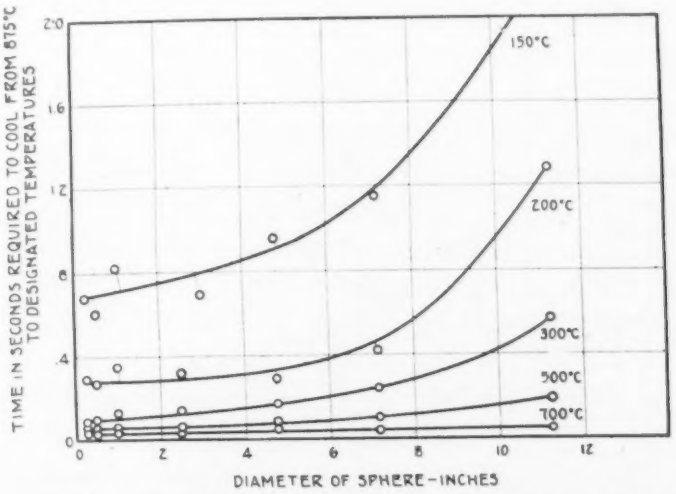


Fig. 20—Cooling Times for Different Temperature Ranges at the Surface of Spheres of Different Diameters When Quenched Into 5 Per Cent Sodium Hydroxide. Coolant Motion About 3 Feet Per Second. Coolant Initially at 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

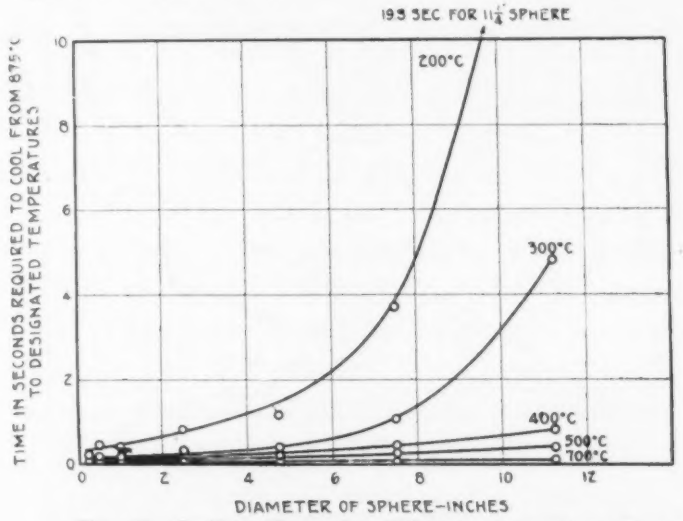


Fig. 21—Cooling Times for Different Temperature Ranges at the Surface of Spheres of Different Diameters When Quenched Into Water. Coolant Motion About 3 Feet Per Second. Coolant Initially at 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

steel may contribute to these periods of instability but it is probable that they are largely associated with the gases which alternately become attached to and are wiped from the metal surfaces during cooling. In aqueous solutions, these gases may include steam

formed at the surfaces of the hot metal, air, carbon dioxide, or other gases released from solution. Gases formed by decomposi-

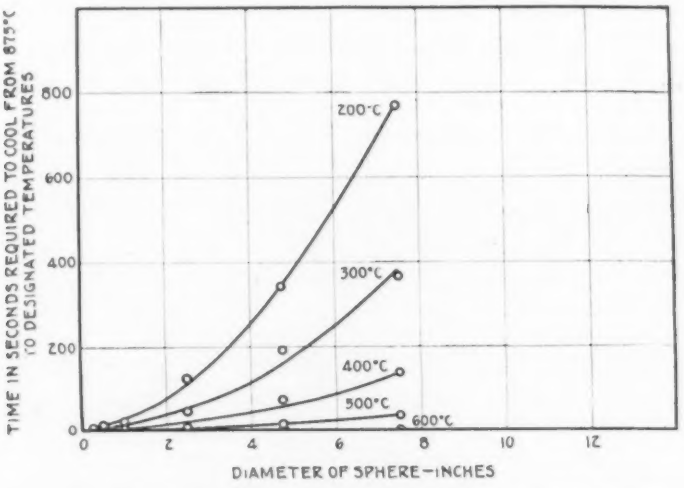


Fig. 22—Cooling Times for Different Temperature Ranges at the Surface of Spheres of Different Diameters When Quenched Into No. 2 Oil. Coolant Motion About 3 Feet Per Second. Coolant Initially at 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

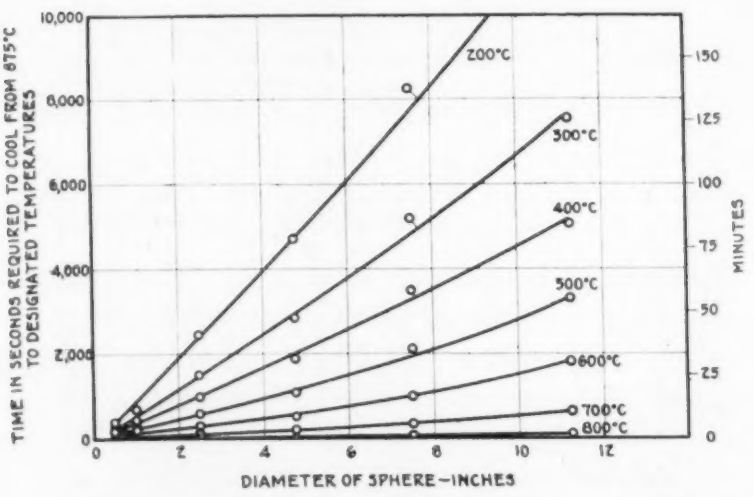


Fig. 23—Cooling Times for Different Temperature Ranges at the Surface of Spheres of Different Diameters When Cooled in Still Air at Atmospheric Temperatures.

tion of the coolant must also be considered in both aqueous solutions and oils.

It is generally believed that gases adhering to heated metal surfaces act as an insulator. In water quenching, a layer of steam plus gases released from solution can be conceived to form momen-

tarily around the specimen soon after it is introduced into the bath. Until these gases are "wiped away" by the flow of the water, the cooling can be retarded. Removal of the jacket of gases would tend to increase the speed of cooling until more gases became attached to the surface to again reduce the rate of heat loss.

Under the customary conditions of quenching it is not unreasonable to assume that this cycle of steam formation and removal would occur at very rapid rates and produce the temperature fluctuations illustrated in Fig. 19.

From the viewpoint of practical heat treatment, these effects show the necessity of selecting coolants which give average cooling rates well above the critical cooling rates of the steel to be hardened. This really represents a safety factor with respect to uniformity in hardening, and may be achieved in at least two ways. The first is to vary the coolant composition, and the second is to provide adequate circulation and volume of the coolant. More detailed discussion of both of these subjects will be given in subsequent sections of this report.

2. *Effect of size on cooling times in different media*

A summary of the effects of size upon the surface cooling of spheres immersed in different coolants is given in Figs. 20 to 23 inclusive. Except in the case of air cooling, increase in size produced relatively small increases in the time required for the temperature to drop from 875 degrees Cent. (1605 degrees Fahr.) to around 600 degrees Cent. (1110 degrees Fahr.). In other words the initial portions of the surface cooling curves are very nearly the same for the spheres of different diameters when quenched in 5 per cent sodium hydroxide, water, or the oil. This is to be expected, since for a short time, the only part of the sphere which is falling appreciably in temperature is an outer layer, the thickness of which is small in comparison with the radius. Furthermore, the conditions of circulation of these coolants were not exactly the same in the early and late stages of cooling since the specimen was being lowered rapidly within the bath for a short period subsequent to immersion. The differences observed under these conditions may, therefore, be considerably smaller than would have been observed if the rapid motion of the

specimen relative to the coolant during immersion could have been avoided.

Much larger differences are produced by variations in the sphere diameter when larger cooling intervals are considered, such

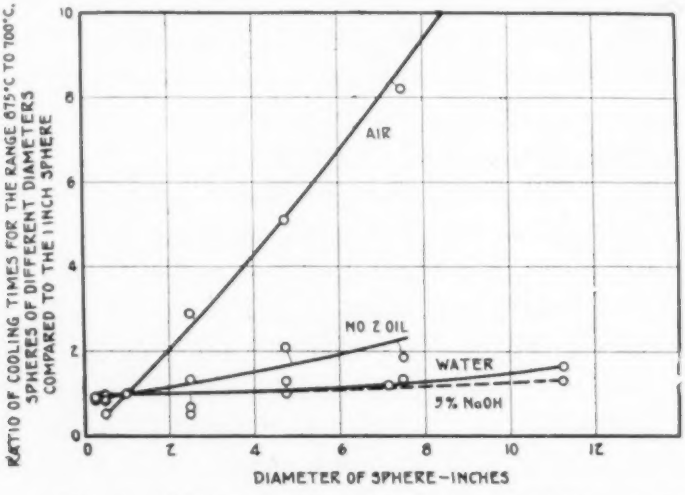


Fig. 24—Effect of Sphere Diameter on the Surface Cooling Times for the Range 875 to 700 Degrees Cent. (1605 to 1290 Degrees Fahr.) When Cooling in Different Media. Chart Based on Data in Figs. 20 to 23 Inclusive.

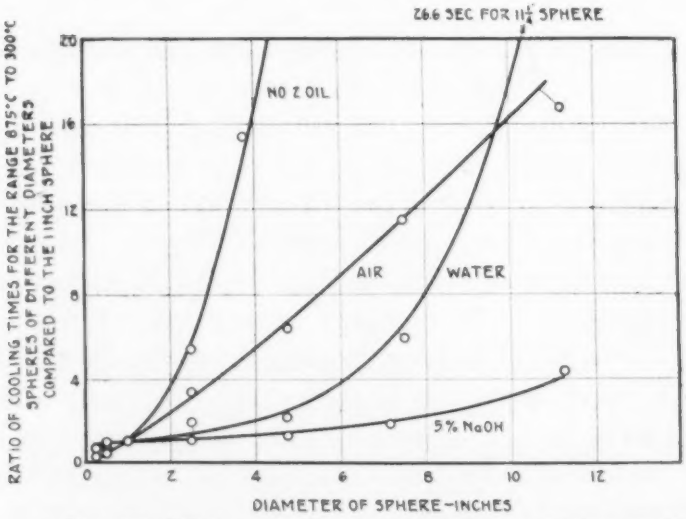


Fig. 25—Effect of Sphere Diameter on the Surface Cooling Times for the Range 875 to 300 Degrees Cent. (1605 to 570 Degrees Fahr.) When Cooling in Different Media. Chart Based on Data in Figs. 20 to 23, Inclusive.

as 875 to 200 or 300 degrees Cent. (1605 to 390 or 570 degrees Fahr.). In such cases, there was a definite increase in the time required for the surface to reach a selected temperature as the

sphere diameter increased. However, large differences in cooling times were observed only in the large specimens comprising spheres 4¾ inches or more in diameter.

An unexpected effect was observed in water quenching. As shown in Table II, the average cooling of the surface from 875 degrees Cent. (1605 degrees Fahr.) to about 600 degrees Cent. (1110 degrees Fahr.) was more rapid in the 2½ inch spheres than in the 1 inch spheres and likewise more rapid in the 1 inch spheres than in the ½ inch spheres. It is difficult to reproduce results in these small specimens, for reasons already discussed, but these effects were observed so consistently upon repeating the experiments that they probably have some significance.

An observation made by Heindlehofer[8] tends to support the view that these effects are real and not solely the result of imperfect control of the conditions of quenching. Heindlehofer calculated the values of surface emissivity from center cooling curves of two silver cylinders, respectively, 2 centimeters and 0.6 centimeters in diameter. These values were much larger for the larger cylinder. He concluded that the specific surface emission[9] "seems also to depend on the absolute size of the quenched object, smaller sizes having smaller specific emission. This would point to a difficulty in obtaining very great quenching speeds by trying to reduce the diameter of the quenched specimen."

3. *Cooling rates*

Since the hardening of steels is related to the rates at which the metal is brought through the transformations, it is of interest to examine the cooling rates at the surface of the spheres.

The most rapid surface cooling, at temperatures around 700 degrees Cent. (1290 degrees Fahr.), was observed when quenching in 5 per cent sodium hydroxide. The rates of cooling varied from about 12,000 to 3,000 degrees Cent. per second for spheres from ¼ to 11¼ inches in diameter.

When quenching in water, with the moderate circulation used in all the experiments (approximately 3 feet per second),

[8] K. Heindlehofer: Quenching: A Mathematical Study of Various Hypotheses on Rapid Cooling, *Physics Review*, 2 series, Vol. 20, 1922, p. 221.

[9] Loss of heat at surface in calories per second, per square centimeter of surface, per degree difference in temperature of surface and coolant.

the cooling rates at temperatures in the neighborhood of 700 degrees Cent. varied from around 8,000 to 1,000 degrees Cent. per second in spheres from ½ to 11¼ inches in diameter. However, the surface did not drop instantaneously to the coolant temperature as is assumed in some theoretical derivations of cooling curves. This condition was approached more nearly when quenching in 5 per cent sodium hydroxide.

As shown in Figs. 15 and 16, the first rapid cooling in either water or 5 per cent sodium hydroxide did not continue to coolant

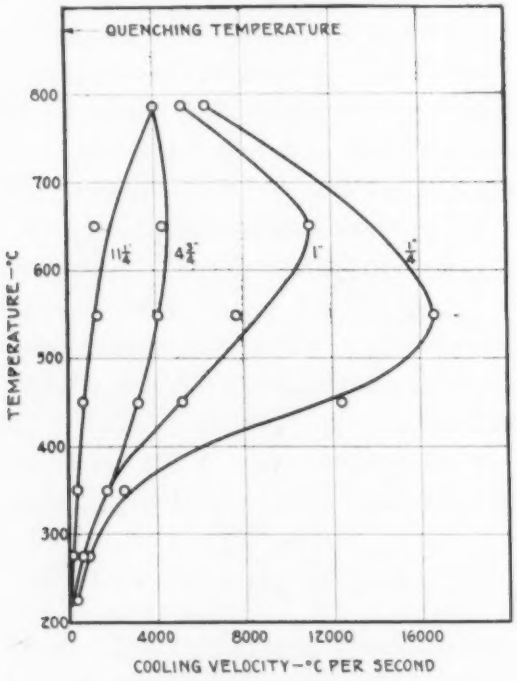


Fig. 26—Effect of Sphere Diameter on the Relation Between Surface Temperature and Cooling Velocity in 5 Per Cent Sodium Hydroxide. Coolant Motion About 3 Feet Per Second. Coolant Temperature 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

temperatures. Instead there was an abrupt change in the slope of the cooling curves at temperatures well above the boiling point of water. The temperatures at which this change occurred increased with increase in the diameter of the sphere and were higher in water quenching than in quenching in 5 per cent sodium hydroxide.

Similar characteristics were shown in oil quenching although here the rates of temperature change at the surface were lower

than in the aqueous solutions, and the change from relatively rapid cooling to slow cooling was less abrupt and occurred at somewhat higher temperatures, in the neighborhood of 500 degrees Cent. (930 degrees Fahr.).

These results throw some doubt on the accuracy of calculations based on the assumption of instantaneous cooling of the

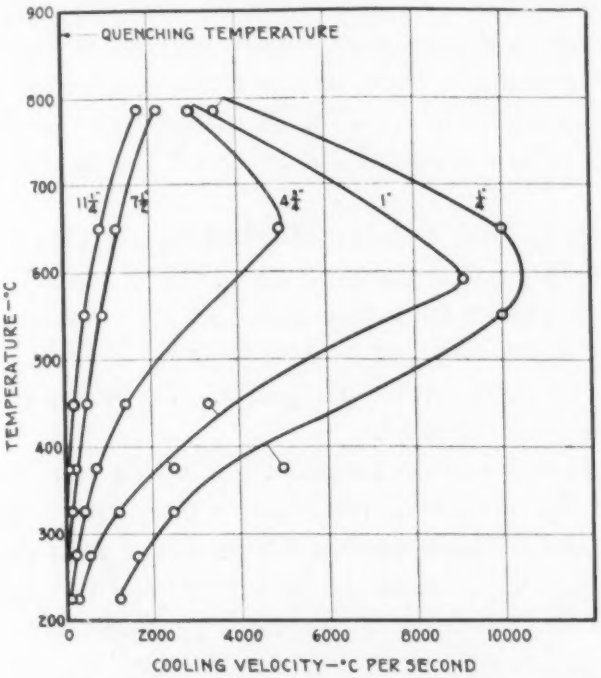


Fig. 27—Effect of Sphere Diameter on the Relation Between Surface Temperature and Cooling Velocity in Water. Coolant Motion About 3 Feet Per Second. Coolant Temperature 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

surface to coolant temperatures. It would be more reasonable to assume instantaneous cooling to some higher temperature even for such rapid coolants as the 5 per cent sodium hydroxide solution. But as shown by the experiments this temperature varies with the size of the piece.

f. Comparison of the coolants in relation to size of sphere

The rates of cooling in the temperature range around 700 degrees Cent. (1290 degrees Fahr.) are of particular interest since it is in this range of temperature that ordinary carbon steels "acquire their desire to harden." It will, therefore, be of interest

to examine the proportional increase in cooling times for different temperature ranges in the different media when the size of sphere is increased. Fig. 24 shows the proportional increase in cooling times for the temperature range 875 to 700 degrees Cent. (1605 to 1290 degrees Fahr.), and Fig. 25 a corresponding summary for the range 875 to 300 degrees Cent. (1605 to 570 degrees Fahr.).

For the short high temperature range the increase in cooling time with increase in diameter of sphere was much larger in the slow coolants, air and oil, than in the rapid coolants, water and 5 per cent sodium hydroxide. Fig. 24 shows that the magnitude of the effects of size decreased in order of the rapidity of the coolants.

The situation is a little different when considering the larger cooling range, 875 to 300 degrees Cent. (1605 to 570 degrees Fahr.). Fig. 25 shows that the cooling times increased more rapidly in water than in 5 per cent sodium hydroxide or air for large increases in the diameter of sphere. However, the largest effects were found with the oil.

This means that 5 per cent sodium hydroxide can be effective in increasing the depth of hardening (or in procuring full hardening) at the surface of large masses where water fails to produce the desired effects. This is not to be interpreted to apply to all sizes but should be valid for a moderately wide range of sizes encountered in industrial work. This further involves the assumption that the circulation of the coolant is moderate and comparable in the case of the two coolants.

Such differences in surface cooling of large masses are not necessarily reflected at interior points. As shown in a previous publication[10] appreciable increases in size tended to reduce the differences in center cooling between water and 5 per cent sodium hydroxide.

Further information on the effects of size upon the surface cooling in the different media may be obtained from Figs. 26 to 29 inclusive. In these charts the average cooling rates for different temperature ranges are plotted against the mean temperatures of the respective ranges.

In both oil and air the maximum rates of cooling were found to be very close to the initial (quenching) temperature and the

[10]See foot note 3.

rates steadily decreased with decrease in the temperature of the surface.

In water and 5 per cent sodium hydroxide the cooling rate-temperature curves (Figs. 26 and 27) showed maximum cooling rates at different temperatures. For spheres of small diameter, around ¼ to 4¾ inches, the maximum cooling rates were found at relatively low temperatures in the neighborhood of 500 to 700

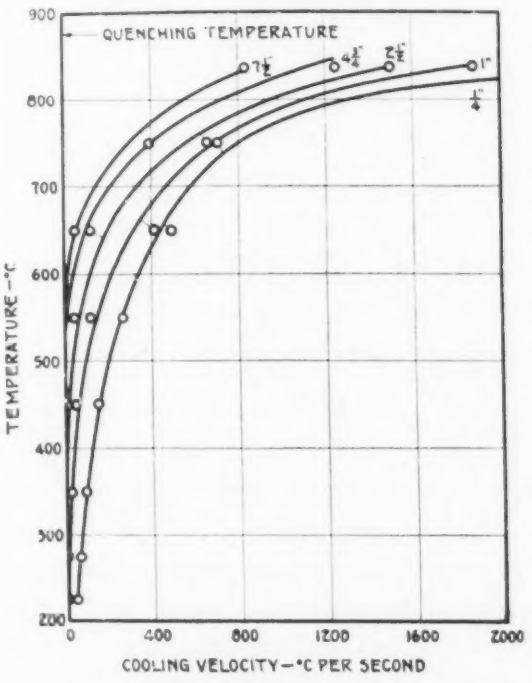


Fig. 28—Effect of Sphere Diameter on the Relation Between Surface Temperature and Cooling Velocity in No. 2 Oil. Coolant Motion About 3 Feet Per Second. Coolant Temperature 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

degrees Cent. (930 to 1290 degrees Fahr.). With increase in size, the temperatures of maximum cooling rates tended to approach the initial temperature so that the curves assumed a form like that of curves for oil and air. This change occurred in smaller spheres when quenching in water than when quenching in 5 per cent sodium hydroxide.

These results are of practical interest since they indicate that no appreciable increase can be expected in the surface cooling rates of large masses, at temperatures around 700 degrees Cent. (1290 degrees Fahr.), by raising the quenching temperature. In

small pieces, immersed in water or 5 per cent sodium hydroxide, increase in the quenching temperature should be effective in increasing the rates of cooling around 700 degrees Cent. (1290 degrees Fahr.). This, of course, is based on the assumption that increase in the initial temperature will produce, at least roughly, a proportional change in the temperature at which the maximum

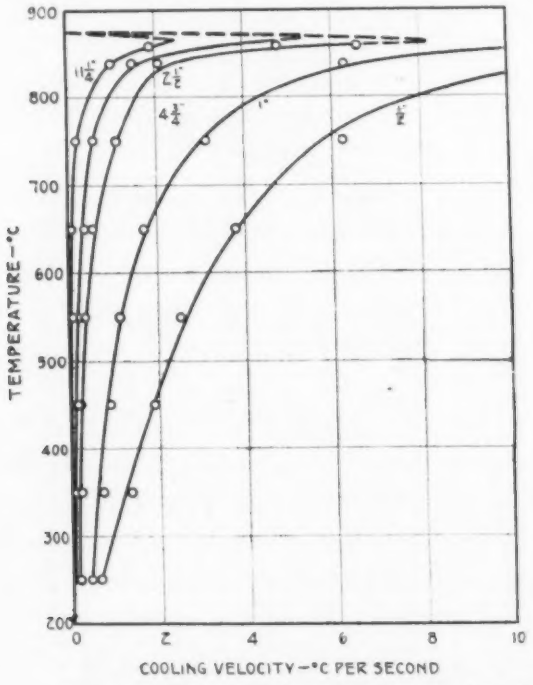


Fig. 29—Effect of Sphere Diameter on the Relation Between Surface Temperature and Cooling Velocity in Still Air at About 20 Degrees Cent. (65 Degrees Fahr.).

cooling rates are observed as it did in the experiments on center cooling.[11] Since the cooling rates at temperatures around 700 degrees Cent. (1290 degrees Fahr.) play a major part in the hardening produced in carbon steels, an increase in the quenching temperature can increase the depth of hardening in small sizes but not appreciably in large sections.

V. Other Factors Affecting Surface Cooling

A quantitative evaluation of the effects of size on surface cooling is hardly justified since the experiments already described were representative only of commercial practice and were not

[11]See foot note 2.

controlled with respect to all of the variables suspected of affecting the removal of heat at the surfaces of the specimens.

Study of the effects of the many variables which can be conceived to affect the cooling is a task of considerable magnitude and

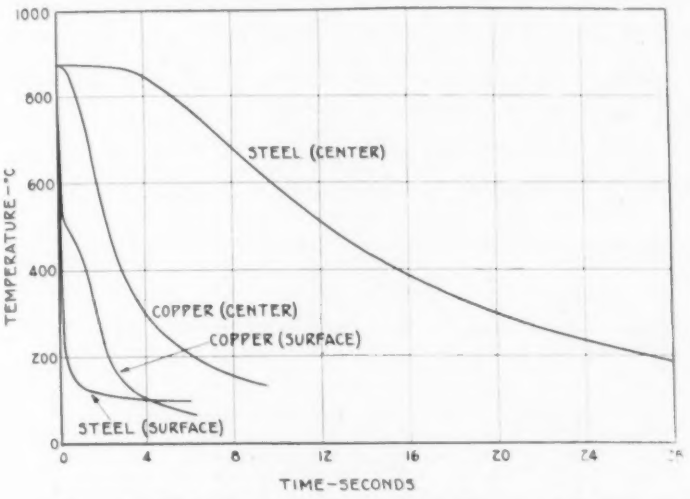


Fig. 30—Surface and Center Cooling Curves of Copper and Steel Spheres 1½ Inches in Diameter When Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water at 20 Degrees Cent. (65 Degrees Fahr.). Coolant Motion Approximately 3 Feet Per Second.

would necessitate surmounting numerous experimental difficulties. A complete survey was not attempted but in the course of the previous experiments questions arose which made it desirable to consider certain of the less generally recognized phases of the subject. Variables, such as the temperature of the coolant, which obviously may exert a pronounced effect upon the cooling, were not considered.

1. *Effect of diffusivity on the cooling of metal spheres*

One of the properties of the metal body itself which can be expected to affect the rate of heat loss is the diffusivity. This is defined as the thermal conductivity divided by the product of the specific heat and density.

The diffusivity of carbon steels at atmospheric temperatures[12] is in the range 0.10 to 0.17 cm.^{2} sec.$^{-1}$. Providing no constitutional changes are involved, the diffusivity tends to decrease as the tem-

[12]Landolt, Boernstein, Roth, Scheel, Physikalisch-Chemische Tabellen. 5. Auflage, Vol. II, p. 1309.

perature increases and available data indicate that the differences in values for different steels tend to decrease.

From theoretical considerations a steel with high diffusivity may be expected to lose heat somewhat more rapidly at the center or other interior points of the body than a steel with low diffusivity but its surface should lose heat at about the same or a slower rate. In other words, metal of high diffusivity may be conceived to feed more quickly to the surface the heat which is in the interior and so tend to decrease the rate of temperature change at the surface.

As already indicated, carbon steels of different carbon con-

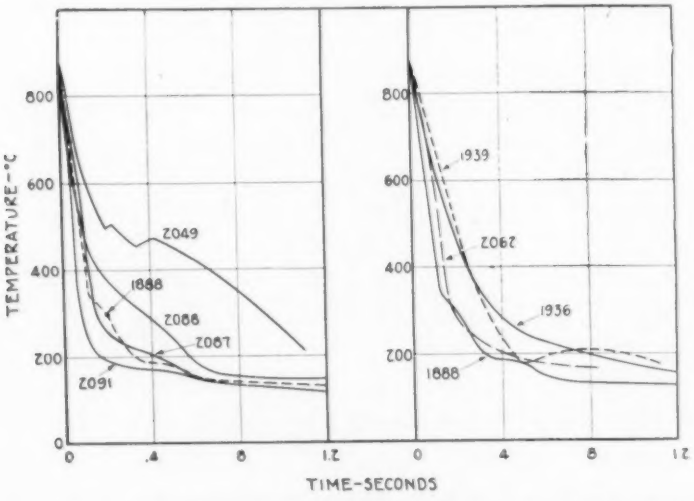


Fig. 31—Effect of Manner of Heating on the Surface Cooling Curves for a 1-Inch Sphere Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at About 3 Feet Per Second. Test 1888—Steel Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 1936—Steel Heated in Illuminating Gas, Held 10 Min. at 875 Degrees Cent. (1605 Degrees Fahr.). Test 1939—Steel Heated in Nitrogen, held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2049—Nickel Plated Steel, Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 206—Steel Heated in Muffle Containing Sawdust, held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2087—Blued Steel, Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2088—Steel Heated in Air, Held 1 Hour at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2091—Steel Heated in Salt Bath, for 10 Min. at 875 Degrees Cent.

tents probably do not differ very widely in diffusivity at given temperatures. Copper has roughly ten times the diffusivity of carbon steels at atmospheric temperatures. While its surface conductivity differs from that of steels, comparison of the surface and center cooling curves of copper and steel spheres offers a means for developing the magnitude of the effects which may be expected.

Table VI

Effect of Surface Condition on the Cooling at the Surface of 1-inch Spheres Quenched in Water[1]

Condition of Surface when Quenched	Condition of Surface after Quench	Heated in Air 10 Minutes and Quenched
	Heavily Oxidized Samples	
Blued by heating 1 hr. at 750 degrees Fahr. (400 degrees Cent.) in 8-KNO_3, 1-MnO_2 (by weight)	Heavily oxidized but less pitting than with usual method.	Little difference
Held 1 hr. in open furnace at 1605 degrees Fahr. (875 degrees Cent.) before quenching	Heavily oxidized.	Little difference
	Surface Oxidation Minimized	
Heated in furnace containing sawdust	Cleaner than with usual method.	Slow, especially at 350 to 600 degrees Cent.
Heated in nitrogen	Cleaner than with usual method—less pitting—Adherent oxide.	
Heated in illuminating gas	Carbon deposit on samples; otherwise like samples heated in nitrogen.	Slow, possibly due to carbon deposit on surface
Heated in salt bath, equal parts by weight of $CaCl_2$ and $BaCl_2$	Very clean.	Rapid—like brine quenching
	Plated Specimens	
Nickel plated (approx. 0.001" coating)	Adherent scale.	Slow over entire temperature range

[1]All samples quenched from 875 degrees Cent. (1605 degrees Fahr.) in water at 19-22 degrees Cent. and moving at 3 feet per second.

Results have already been reported[13] which showed that the center of a copper cylinder, ¾-inch in diameter, and 3 inches long, cooled roughly 50 per cent faster in the neighborhood of 700 degrees Cent. (1290 degrees Fahr.) than the center of a steel cylinder of similar dimensions when both were quenched from 875 degrees Cent. (1605 degrees Fahr.) into motionless water at 20 degrees Cent. (65 degrees Fahr.). Fig. 30, representing the cooling curves of copper and steel spheres, 1½ inches in diameter, confirms the very much more rapid cooling at the interior of the copper body. On the other hand, the surface of the copper sphere cooled more slowly than that of the steel sphere to temperatures in the neighborhood of 150 degrees Cent. (300 degrees Fahr.). The differences were not marked until temperatures around 500 degrees Cent. (930 degrees Fahr.) were reached when the surface of the copper sphere showed a marked increase in cooling times. Crossing of the surface curves at about 100 degrees Cent. (210

[12]See foot note 2.

degrees Fahr.) may be ascribed in part to the heat of transformations in the steel.

The differences in diffusivity of commercial carbon and low alloy steels which are ordinarily hardened by water quenching are only a fraction of the differences between steels and copper. Therefore, variations in the cooling curves of such steels may be expected to be small in most cases. As will later be shown such

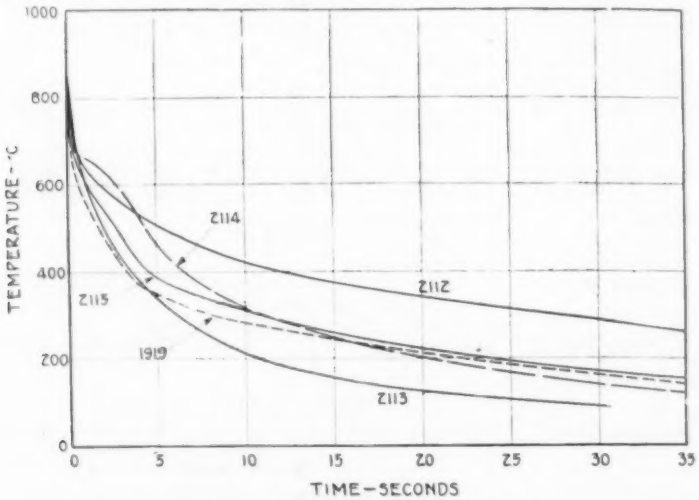


Fig. 32—Effect of Manner of Heating on the Surface Cooling Curves for a 1-Inch Sphere Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into No. 2 Oil at 20 Degrees Cent. (65 Degrees Fahr.), Moving at About 3 Feet Per Second. Test 1919—Steel Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2112—Steel Heated in Air, Held 1 Hour at 875 Degrees Cent. (1605 Degrees Fahr.). (Note Adhering Scale.) Test 2113—Steel Heated in Air, Held 1 Hour at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2114—Nickel Plated Steel, Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2115—Steel Heated in Nitrogen, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.).

differences are much less important than variations which may be introduced by the manner in which the quenching operation is carried out. However, an increase in diffusivity of the metal quenched should tend to increase the speed of cooling at the center and decrease it at the surface of the body.

2. *Effect of surface condition of the metal on the cooling*

a. Oxidation

Most of the experiments already described were repeated one or more times on the same samples without attempting to remove the adhering oxide from the previous heating and cooling.

Frequently, though not invariably, the first cooling was somewhat slower than the second, third, or succeeding coolings. However, in some cases the most rapid cooling was observed the first time.

Such variations might originate from one or both of the following causes; (1) Change in thermal properties of the steel resulting from structural changes brought about by the previous heating and cooling, (2) Variations in the condition of the surface of the metal samples, especially with respect to scale thickness and adherence of the oxide to the underlying metal.

The comparisons of copper and steel spheres, just cited, indicate that the surface cooling should not be appreciably affected by any changes which can normally be expected in the thermal properties of steels at high temperatures. Practical experience indicates that surface cooling can be appreciably affected by the condition of the metal surfaces.

Cooling curves were taken on heavily oxidized samples and on samples so heated as to minimize the oxidation of the surfaces of the spheres. Tests were also made on nickel plated spheres and the results are summarized in Table VI and Figs. 31, 32, and 33.

Several methods were used to minimize oxidation in heating. Samples were heated in a muffle containing sawdust, in a salt bath and in atmospheres of nitrogen or illuminating gas. Heavily oxidized samples were prepared by bluing in potassium nitrate mixed with manganese dioxide and by long heating at the hardening temperatures before quenching.

Although oxidation during heating was minimized by the illuminating gas and nitrogen atmospheres, it should not be assumed that the samples were clean and free from all oxide. Oxidation can take place during cooling in water where the highly heated steel is momentarily in contact with steam, gases originally in solution, or those resulting from the decomposition of the coolant. Furthermore, the heated steels (except samples heated in salt) were momentarily in contact with air during transfer from the furnace to the coolant.

Fig. 31 shows that the surface cooling of the heavily oxidized samples when immersed in water did not differ appreciably from that of the samples heated for the normal short period in air. On the other hand, the surface cooling of the nickel plated spheres

Fig. 33—Photographs of the Oil Quenched Spheres Referred to in Fig. 32. × 1.

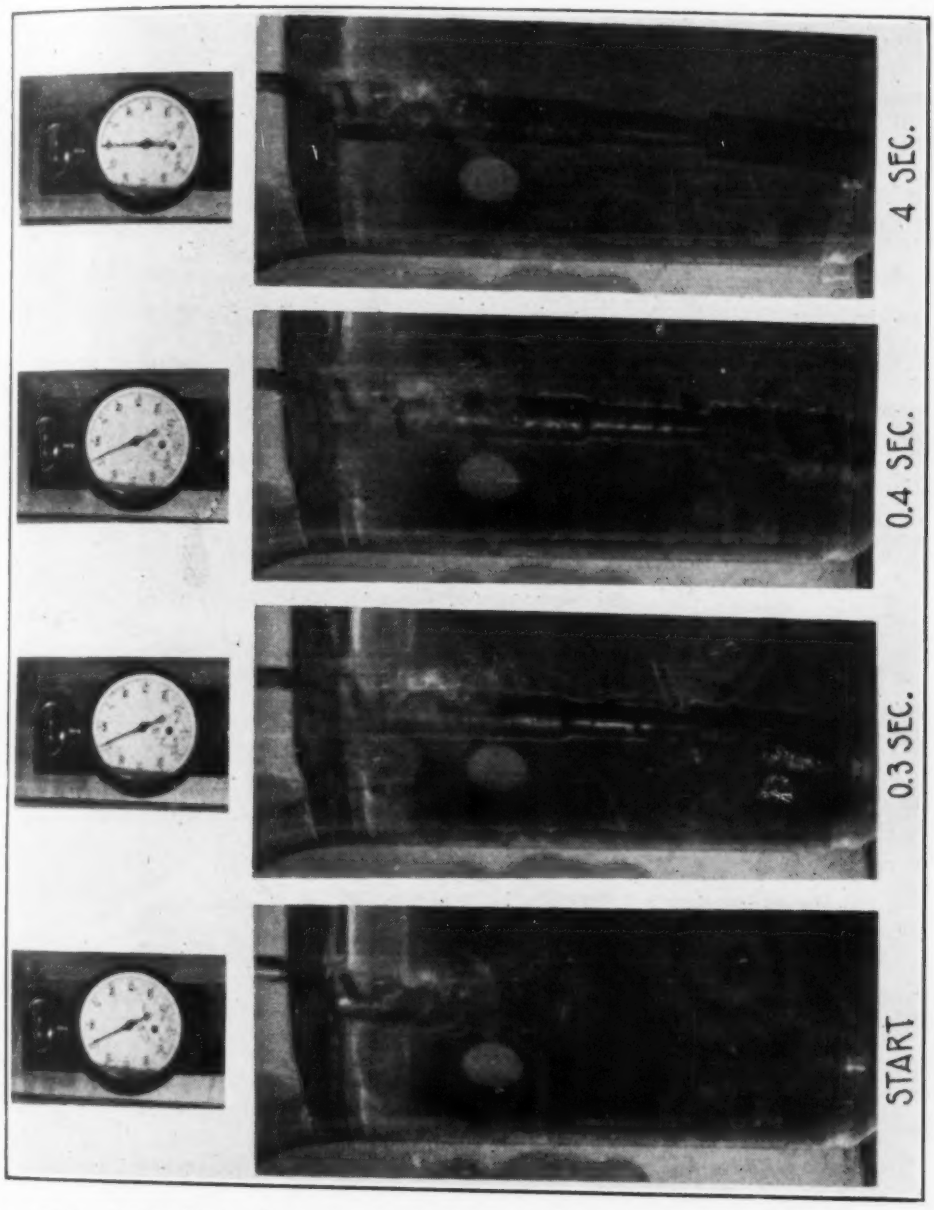


Fig. 34—Photographs Taken During Quenching of a ½-Inch Diameter by 2-Inch Steel Cylinder Quenched in Motionless Water at About 20 Degrees Cent. (68 Degrees Fahr.). The Cylinder Was Quenched at 875 Degrees Cent. (1605 Degrees Fahr.). Compare the Evolution of Gas and Distance Traveled by the Scale Blown Off the Specimen with Similar Effects in Sodium Hydroxide.

was somewhat slower than that of the corresponding unplated samples, but the differences were small. The nickel was deposited on the spheres subsequent to welding the thermocouples to the surface of the steel and this may have had the effect of placing the thermal junction enough below the surface in contact with the coolant to increase the recorded cooling times. However, it should be noted that the nickel oxide produced in heating the samples remained more nearly intact and was not so easily detached from

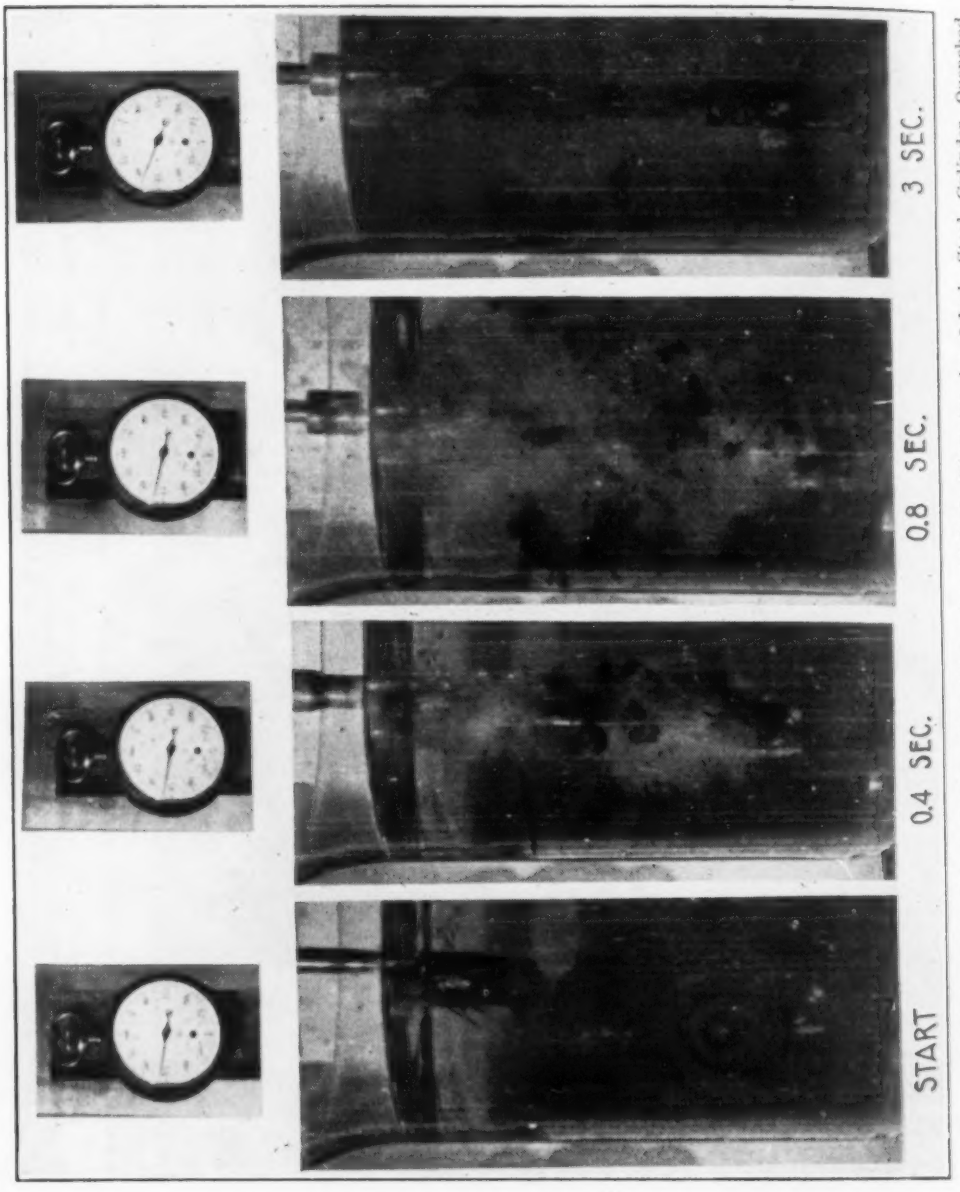


Fig. 35—Photographs Taken During Quenching of a ½-Inch Diameter by 2-Inch Steel Cylinder Quenched in 5 Per Cent Sodium Hydroxide. The Cylinder was Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) with the Motionless Coolant at About 20 Degrees Cent. (65 Degrees Fahr.). Note Particularly the Violent Action and the Distance Traveled by the Scale Blown Off the Specimen.

the underlying metal when immersed in water as was the iron oxide scale on the unplated spheres. If the predominating cause of reduced speeds of cooling is the insulating effect of a complete envelope of oxide, considered to have low thermal conductivity, or due to a loosely adherent scale which tends to trap gases, then heavily oxidized samples should show slower cooling, at both surface and center, than slightly oxidized samples, if quenched in

coolants which do not tend to break up the continuity of the iron oxide film.

Center cooling curves for spheres quenched in oil, which are reproduced in Fig. 32, show this to be the case and when compared with photographs of the quenched specimens, in Fig. 33, furnish a striking illustration of possible effects of adherent oxide. For example, samples 2112 and 2113, Fig. 33, were heated and quenched in the same manner. In 2112 the scale was left as an

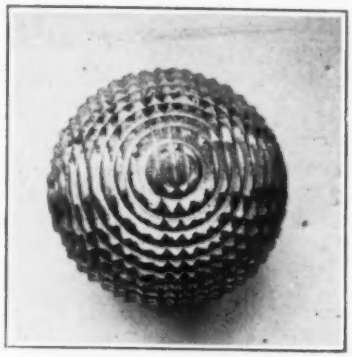


Fig. 36 — Photograph of the Knurled Sphere Used. × 1.

envelope around the sample, whereas in the duplicate specimen, 2113, most of the scale was broken off. The cooling curves in Fig. 32 show that the sample with the scale envelope cooled very much more slowly (test 2112) than the duplicate (test 2113) in which the scale was broken off in the coolant.

The differences in Fig. 32 are not all so large as in the case mentioned, but there are wide variations in the cooling curves which clearly indicate that the manner of cooling may be appreciably affected by the character of the oxides at the surfaces of the pieces.

In practical heat treatment such conditions are reflected by lack of uniformity of results and, depending upon the size and shape of the parts and composition of the steel under treatment, may make it difficult to secure the desired hardness. Such effects would be most important in sizes in which only surface hardening can be obtained with the selected steels and coolants. However, lack of uniform hardening in steels generally introduces the problem of internal stresses and when the stresses, hardness and cooling curves can be correlated a better conception will be obtained of the

Fig. 35—Photographs Taken During Quenching of a ½-Inch Diameter by 2-Inch Steel Cylinder Quenched in 5 Per Cent Sodium Hydroxide. The Cylinder was Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) with the Motionless Coolant at About 30 Degrees Cent. (65 Degrees Fahr.). Note Particularly the Violent Action and the Distance Traveled by the Scale Blown Off the Specimen.

importance of the described differences in the cooling curves.

A carbon deposit was obtained on most of the samples heated in illuminating gas which decreased the speeds of surface cooling on water quenching. There was little difference in the cooling curves obtained on samples heated for short periods in air and those heated in the presence of sawdust or in an atmosphere of nitrogen. However, there was a tendency toward retarded cooling on samples heated in nitrogen.

These samples did not have a heavy scale but showed evidence

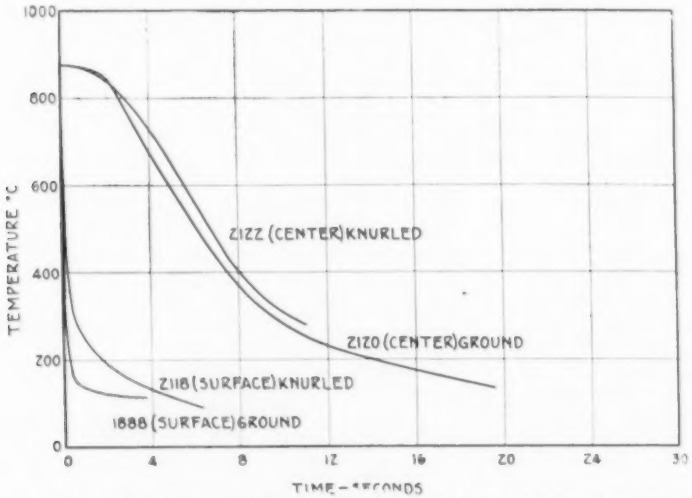


Fig. 37—Center and Surface Cooling Curves of Smooth Ground and Knurled 1-Inch Spheres Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water at 20 Degrees Cent. (65 Degrees Fahr.). Coolant Motion About 3 Feet Per Second.

of oxidation of a type which adhered tenaciously to the underlying steel. This substantiates the view that oxide retards the cooling only when it adheres to the metal. Slight oxidation accompanied by good adherence, or heavy adherent scale such as might be expected on some nickel steels, tends to retard cooling even in water quenching. Scale, which is readily blown off by gas evolution in aqueous solutions, does not seem to effect the cooling appreciably. All oxide coatings become of more importance in less drastic media in which the conditions tend to preserve the continuity of the coating.

The fact that scale is actually blown off the surface of the steel when quenching in water and aqueous solutions can readily be shown if the quenching is carried out in a glass container. Figs. 34 and 35 containing enlarged photographs from motion picture

films taken through a glass tank illustrate the features mentioned. It will be noted that the action is very much more violent in 5 per cent sodium hydroxide than in ordinary tap water and is accompanied by a wider distribution of gas and turbulence. The photographs show one of the features which probably contribute to the uniformity obtained in practice with sodium hydroxide solu-

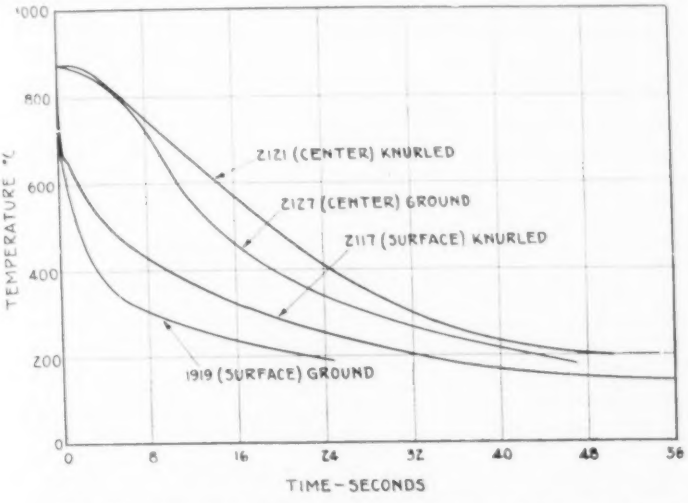


Fig. 38—Center and Surface Cooling Curves of Smooth Ground and Knurled 1-Inch Spheres Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into No. 2 Oil at 20 Degrees Cent. (65 Degrees Fahr.). Coolant Motion About 3 Feet Per Second.

tions since their relatively violent action in contact with hot steel tends to compensate for deficiencies in circulation.

One of the interesting features shown in Table VI and Fig. 31 is the comparison of the water cooling of samples heated in air and those heated in the salt bath. The latter cooled in appreciably shorter time than the former and the quenched sphere was relatively clean and looked like steel which had been heated in air and quenched in 5 per cent sodium hydroxide. The increased speed of cooling of the samples heated in the salt bath may be ascribed to the elimination of scale in the heating and to the solution of the adhering salt by the water adjacent to the hot metal upon introduction into the coolant. The importance of the latter effect is indicated by the fact that the cooling at the surface of the sample heated in salt and quenched in water was about the same as that of steel heated in air and quenched in 10 per cent sodium or calcium brines.

Apart from possible insulating effects, oxide may affect the

Table VII

Comparisons of Center Cooling when Quenching ½-inch Diameter by 2-inch Cylinders in Different Oils[1]

Item	Oil	Seconds to cool from 800 to 600 degrees Cent. (1470 to 1110 degrees Fahr.)
1	Pale neutral oil	6.3
2	Pale neutral plus 5 per cent residuum	4.3
3	Prepared (commercial) oil No. 2	6.1
4	Prepared (commercial) oil No. 1	5.1

[1]Samples prepared from 0.95 per cent C steel.

cooling in two other ways. Oxidation frequently pits the surface and the irregularities would tend to promote adherence of gas. Oxide even when smooth may differ from steel in its ability to hold gas bubbles formed or released in the coolant during quenching.

b. Smoothness

Brophy[14] has already shown that the degree of roughness of surface may have an appreciable effect upon the results obtained in quenching through variations in the adherence of gas formed in the coolant. Ground samples showed fewer soft spots than samples with surfaces roughened by knurling. This was ascribed to the stronger tendency for gas bubbles to cling to the roughened surface.

Comparisons are given in Figs. 37 and 38 of the center and surface cooling in smooth ground and "knurled" spheres when quenched in water and likewise in oil. The spheres were knurled as illustrated in Fig. 36.

In both oil and water quenching the cooling was slower in the roughened spheres than in those which were ground. The differences were greater in oil than in water quenching and in the latter case were larger for the surface than for the center.

The effects observed in water quenching were probably the result of steam being more readily trapped by the knurled surface; in the case of oil quenched samples it seemed probable that the relatively large differences were due to the combined effects of any trapped gas and adherent scale since the knurled spheres had

[14]General discussion of paper by S. Epstein and H. S. Rawdon: Progress in Study of Normal and Abnormal Steel, TRANSACTIONS, American Society for Steel Treating, Vol. 12, 1927, p. 413.

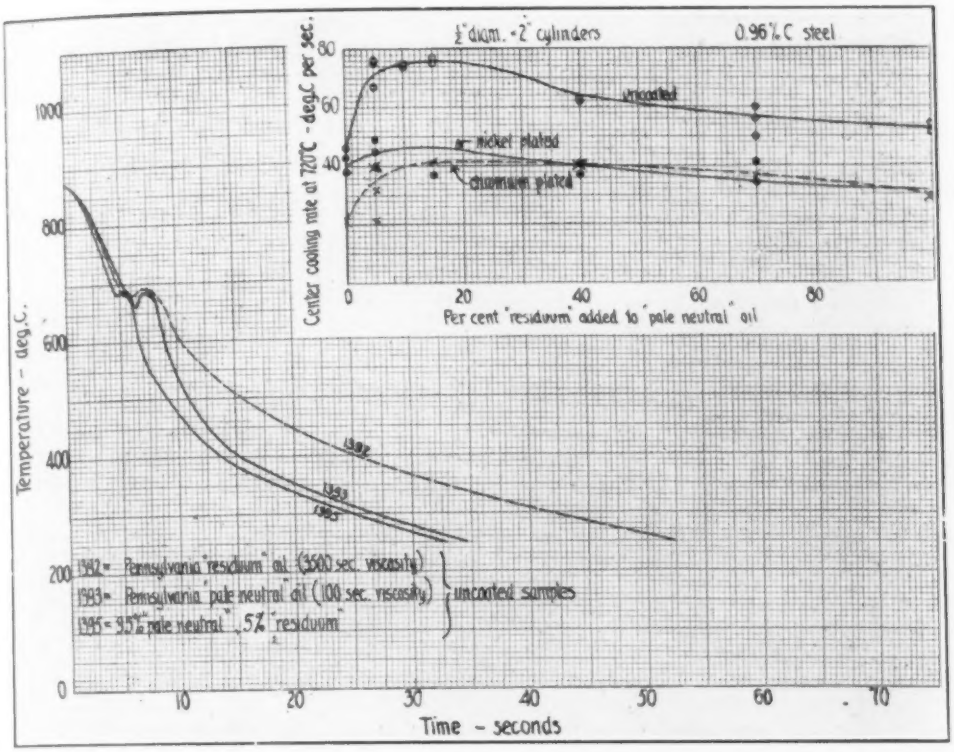

½" diam. × 2" cylinders
0.96% C steel
Center cooling rate at 720°C - deg.C. per sec.
uncoated
nickel plated
chromium plated
Per cent "residuum" added to "pale neutral" oil
Temperature - deg.C.
1982
1983
1985
1982 = Pennsylvania "residuum" oil (3500 sec. viscosity)
1983 = Pennsylvania "pale neutral" oil (100 sec. viscosity)
1985 = 95% "pale neutral" 5% "residuum"
uncoated samples
Time - seconds

Fig. 39—Effect of Additions of Pennsylvania Residuum Oil to Pale Neutral Mineral Oil on the Center Cooling of Steel Cylinders. See Text for Details of These Experiments.

a nearly complete oxide envelope subsequent to quenching. However, in both water and oil the decreases in speeds of cooling resulting from the roughened surface were of sufficient magnitude so that they could contribute to an important degree to lack of uniform hardening in practice.

c. Relation of surface to the oil used

Discussion of the effects of oxidation and smoothness upon the cooling of steel spheres will not dispose of the subject of the influence of the surface conditions upon the cooling of metals. In the course of experiments in which small cylinders were quenched in various oils evidence was obtained that effects produced by variations in the condition of the metal surface might be different in different coolants. In other words, the relation between the metal surface and the coolant, as well as variations in the metal surface, may play a part in determining the manner of cooling.

The cooling curves upon which the following discussion is

based were obtained at the center of cylinders ½-inch in diameter and 2 inches long. The tests were made as the result of a statement by Rodman and Boren[15] that "certain oils of low viscosity and low flash point may have their initial quenching speed materially increased by adding thereto a comparatively small proportion of

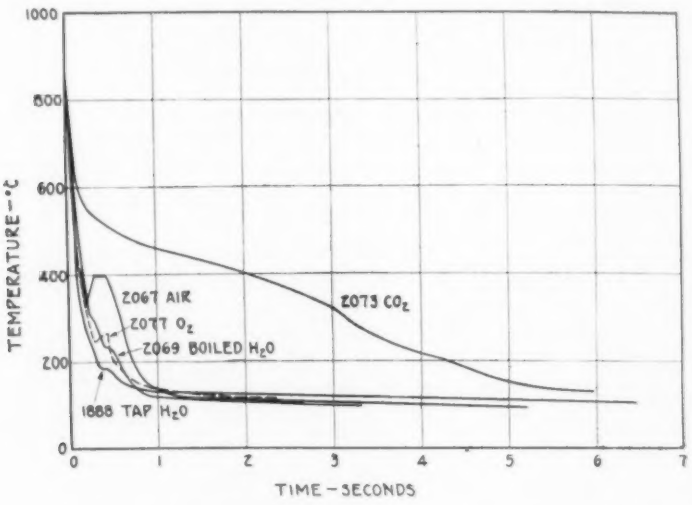


Fig. 40—Effects of Different Dissolved Gases Upon the Surface Cooling in Water Quenching. 1-Inch Steel Spheres Quenched from 875 Degrees Cent. (1605 Degrees Fahr.); the Water was 20 Degrees Cent. (65 Degrees Fahr.) and Moving at About 3 Feet Per Second.

oil of high flash point and high viscosity." As an example, it was stated that there may be added to 100 parts of an ordinary Pennsylvania neutral oil having a viscosity of about 70 seconds at 26.6 degrees Cent. (100 degrees Fahr.), and a flash point of about 177 degrees Cent. (350 degrees Fahr.), about 10 parts of a heavy residuum oil derived from Pennsylvania crudes ("steam refined oil"), having a flash point of about 327 degrees Cent. (620 degrees Fahr.) and a viscosity of about 200 seconds at 100 degrees Cent. (212 degrees Fahr.). It was claimed that such a mixture "will quench red hot steel from about 815 degrees Cent. (1500 degrees Fahr.) down to about 650 degrees Cent. (1200 degrees Fahr.) in less than half the time required by any commercial quenching oil" which could be found on the market.

The idea of adding an oil of high viscosity to one of low viscosity to increase speed of cooling is probably contrary to popular conceptions although it is generally recognized that the speed of

[15]U. S. Patent 1,535,379, April 28, 1925.

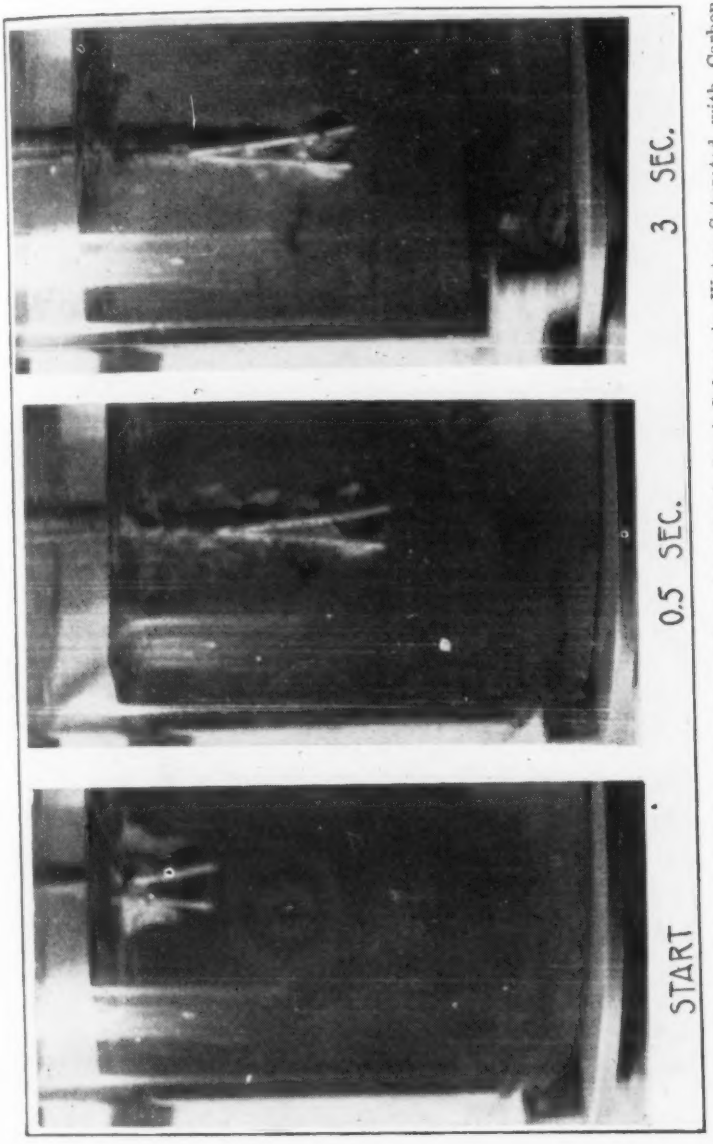


Fig. 41—Photographs Taken During Quenching of a 1-Inch Steel Sphere in Water Saturated with Carbon Dioxide. The Sphere was Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water at About 20 Degrees Cent. (65 Degrees Fahr.). Motion of the Coolant, Produced by Rotation of the Glass Tank, was About 3 Feet Per Second. Note Release of Gas and Pieces of Scale Blown Off the Specimen.

cooling is not solely dependent upon viscosity. As shown in Fig. 39 the speed of cooling in Pennsylvania pale neutral oil of about 100 seconds viscosity (hereafter referred to as "pale neutral" oil) is materially increased at temperatures around 600 to 800 degrees Cent. (1110 to 1470 degrees Fahr.) by the addition of 5 per cent of Pennsylvania residuum oil of about 3500 seconds viscosity (hereafter referred to as "residuum" oil). Similar increases were observed with additions of 10 and 15 per cent of the residuum oil to the pale neutral oil but the magnitude of the effects was some-

what less than was claimed by Rodman and Boren.

Table VII shows the magnitude of these changes in relation to customary commercial quenching oils. Item (1) is the pale neutral oil, (2) the pale neutral oil plus 5 per cent by volume of the residuum oil, (3) a fairly "rapid" commercial quenching oil and (4) the most "rapid" commercial quenching oil tested up to the time the described experiments were made.

Similar results were obtained in quenching chromium plated

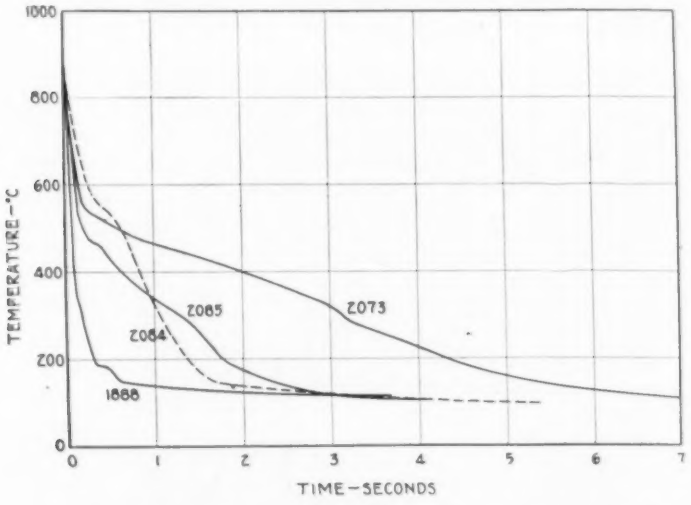


Fig. 42—Effect of Manner of Heating on the Surface Cooling Curves of 1-Inch Spheres Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water Saturated with Carbon Dioxide. Water Temperature 20 Degrees Cent. (65 Degrees Fahr.), Coolant Motion About 3 Feet Per Second. Test 2073—Steel Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2084—Nickel Plated Steel, Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2085—Blued Steel, Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 1888 for Comparison, Represents Steel Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.) and Quenched Into Tap Water.

steel cylinders but the numerical values of the cooling rates (Fig. 39) were all lower than in the uncoated samples. While somewhat irregular results were obtained in corresponding experiments with nickel plated cylinders, there was no appreciable increase in speed of cooling produced by the addition of small proportions of residuum oil to the pale neutral oil.

The results of these experiments raise two questions:—(1) what are the causes of the increased speeds of cooling for the steel cylinders produced by adding small quantities of the heavy oil to the light, and (2) why the same increase in cooling rate was

not observed in samples coated with various metals such as nickel and chromium.

While some further work was done in attempting to find an explanation, none can be advanced with supporting evidence at this time. In any case, it would seem that the answer to both questions will involve the relation between the metallic surface and the coolant.

3. *Effect of Gases Dissolved or Formed in the Coolant*

It is known that the gas adhering to the surface of a metal during quenching may appreciably change the manner of cooling in a given coolant. The result may be a general decrease in the hardness of the quenched steel or the effects may be localized so that the steel is not uniformly hard.[16] The soft spots in such cases may be discolored and seem to indicate a reaction between the metal and the gas with which it was in contact.

Fig. 40, representing surface cooling curves of 1-inch spheres quenched into water containing different amounts and kinds of gases, shows that the magnitude of the effects of dissolved gases may vary widely. In all cases illustrated, the gas was passed through the water for a considerable period to produce saturation at atmospheric temperatures and pressures before quenching.

The cooling curves obtained were practically the same for boiled water, Washington city (tap) water and water saturated with oxygen. Retarded cooling was observed, particularly at temperatures in the neighborhood 400 to 150 degrees Cent. (750 to 300 degrees Fahr.) in water saturated with air but the greatest effects were obtained with water saturated with carbon dioxide. This gas is soluble in relatively large proportions in water and the cooling was very much slower than that in tap water in the range 600 to 150 degrees Cent. (1110 to 300 degrees Fahr.).

The fact that carbon dioxide was the most effective of the gases studied in retarding the cooling may be ascribed in large part to its high solubility in water.

Visible evidence of the possible importance of dissolved gases in water is given in Fig. 41 in which are reproduced photographs from a motion picture taken during the quenching of a 1-inch sphere in water saturated with carbon dioxide. The large evolu-

[16] See reference 14.

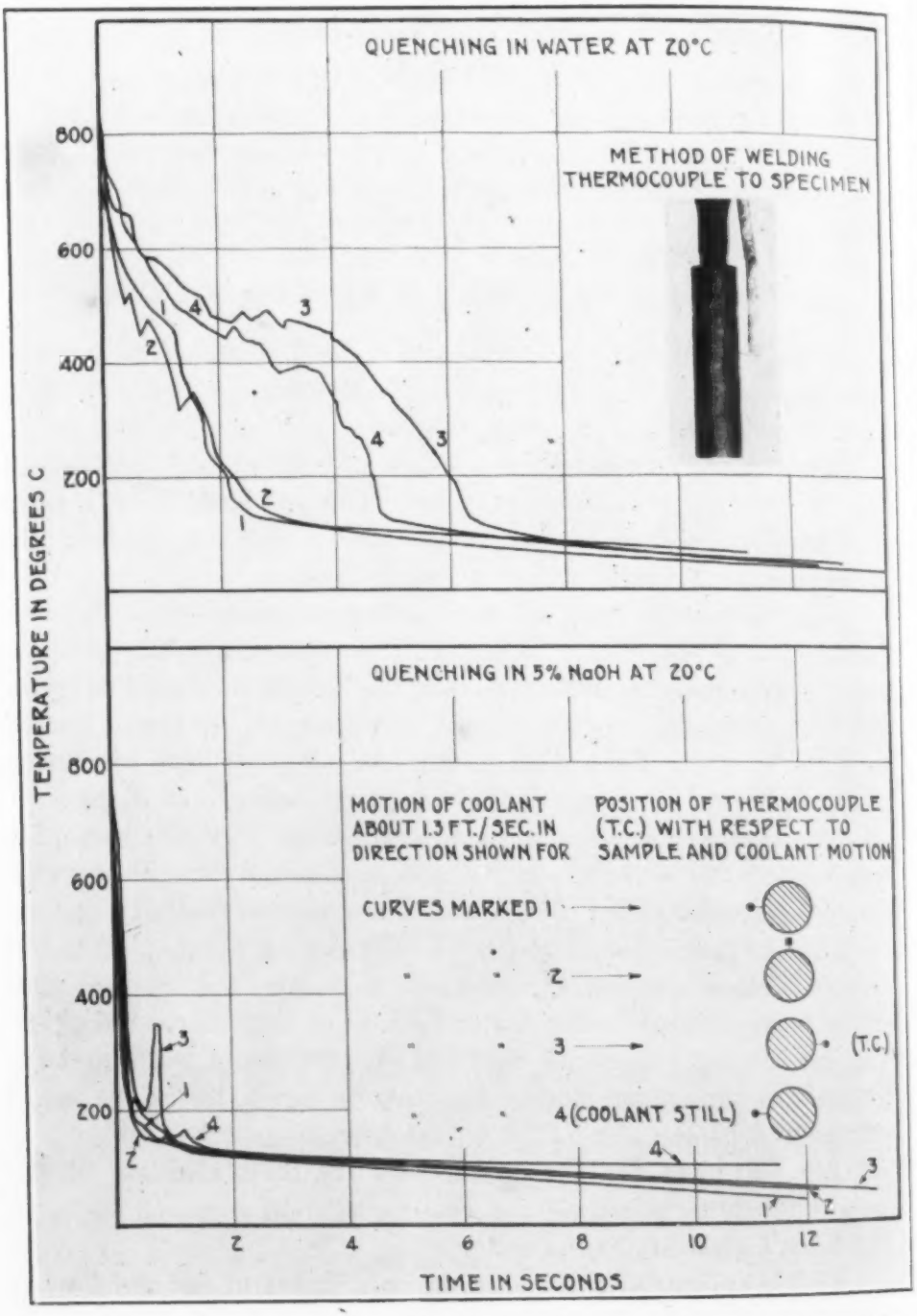


Fig. 43—Cooling at Different Parts of the Surface When Quenching Small Cylinders in a Rotating Bath of Water or 5 Per Cent Sodium Hydroxide. Cylinders ½-Inch Diameter by 2 Inches Long of 0.95 Per Cent Carbon Steel. Temperatures Determined with 32 B and S Gage Thermocouple.

tion of gas continues throughout the major portion of the time of immersion. In contrast with the effects observed in sodium hydroxide solutions (Fig. 35) the action is not violent and it is reasonable to suspect that many gas bubbles have adhered to the surface of the sphere to produce the effects shown in Figs. 40 and 41.

The decrease in speeds of cooling is not the only feature to be

Table VIII

Hardness of the Surface of 0.95 Per Cent C Steel Cylinders at Different Points Around the Circumference when Cooled as Shown in Fig 43[1]

Specimen and Test Number	Average Rockwell Hardness (C Scale) Front	Sides	Back
12048	64.7	59.5 63.4	57.5
12047	57.4	54.6 49.8	54.4
12046	58.6	46.3 48.5	46.0
13001	64.2	63.7 63.9	63.0
Average	61.2([2])	56.2([3])	55.2([2])

[1]Cylinders ½-inch diameter by 2 inches long.
[2]From about 32 hardness tests.
[3]From about 64 hardness tests.

considered. An important characteristic is the instability at the metal-coolant contact surfaces. This is shown both by the character of the cooling curves and by the increased difficulties which were encountered in reproducing results. With respect to the latter, it should be kept in mind that the curves shown in Fig. 40 give an approximation to what happens over only a small spot on the surface. However, the difficulty of reproducing such cooling curves is a reflection of conditions which probably obtain over the entire surface. Lack of uniformity is one of the principal difficulties which can be expected in practical heat treatment when quenching in water containing dissolved gases.

The character of the metal surface may also play a part in the effects produced by given quantities and types of gases. As shown in Fig. 42, representing samples quenched in water saturated with carbon dioxide, the greatest retardation in cooling was obtained in the samples heated in the ordinary manner in air. Less retardation, but equal instability, was observed in the nickel plated

spheres heated in air and in the spheres blued prior to heating in air for quenching.

It is probable that in practical heat treatment the three variables, oxidation, roughness of surface and adhering gas formed by or released from the coolant, go hand in hand and that the dif-

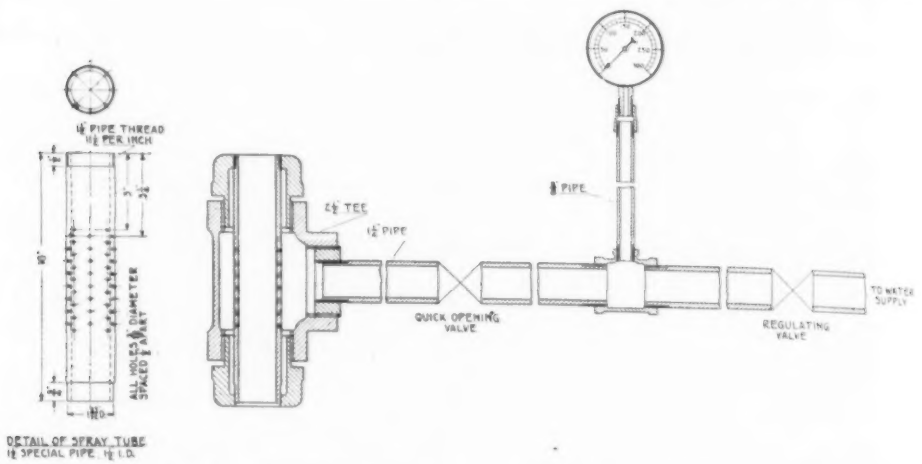


Fig. 44—Sketch of the Equipment Used in High Pressure Water Spray Quenching.

ficulty in procuring the desired hardness is often the result of the combined effects of these three. When neglected they may contribute largely to erratic and non-uniform results but under suitably controlled conditions the magnitude of their effects may be considerably decreased.

4. Circulation of the Coolant

A factor of great practical importance is the circulation of the coolant or its converse, the motion of the sample with respect to the coolant. In considering this subject, attention should be given not only to the circulation subsequent to immersion but also to the flow around the steel as it is being lowered within the coolant. This latter has special significance in the case of small pieces immersed in rapid coolants such as water where the surface of the sample may reach a temperature of 150 degrees Cent. (300 degrees Fahr.) or even less in the time that the sample is being lowered within the bath.

Tests reported by Haler[17] indicate that there is a wide varia-

[17]P. J. Haler: Quenching: A Practical Study on Rapid Cooling, *Mechanical Engineering*, Vol. 49, 1927, p. 1187.

Table IX

Mechanical Properties of 0.07 Per Cent C Steel Quenched in Various Ways from 940 Degrees Cent. (1725 Degrees Fahr.)
(C, 0.07 Mn, 0.27 P, 0.006 S, 0.054 Si, 0.001 Cr, 0.07 (a)

Spec. No.	How quenched	Water Line Pressure lbs. per sq. inch	Prop. Limit	Yield Point	Tensile Strength	Breaking Strength	El. in 2 inches, Per Cent	Red. Area, Per Cent	Area under stress-strain curve, square inch	Izod impact, energy absorbed foot pounds (b)
			Lbs. per square inch							
C6- 1	"As rec'd"		15,000	37,300	47,300	113,000	48.0	74.6	2.20	71, 72, 71 Average 71.3
C6- 2	H_2O bath at 18° C.	none	25,000	45,600	67,400	139,500	24.0	71.1	1.48	83, 84, 76 Average 81.0
C6- 3	H_2O spray,	20	contin. curve	81,200	103,600	164,000	13.5	50.3	1.32	
C6- 4	18° C.	20	32,000	84,500	110,000	160,000	14.0	49.0	1.37	
C6- 5	H_2O spray,	40	38,000	73,900	91,500	166,500	15.5	59.7	1.19	57, 63, 66
C6- 6	18° C.	40	39,000	79,000	102,000	167,000	12.5	52.6	1.20	Average 62.0
C6- 7	H_2O spray,	60	42,000	86,300	112,100	150,000	9.0	36.5	0.89	
C6- 8	18° C.	60	38,500	70,500	96,600	145,000	15.0	46.3	1.31	
C6- 9	H_2O spray,	85	contin. curve	74,200	95,600	170,000	18.0	57.4	1.54	43, 48, 60
C6-10	18° C.	85	28,500	85,000	104,800	148,500	10.0	39.2	0.96	Average 50.3

(a) Tensile specimens had a reduced section approximately 0.435 and 2¼ inches long.
(b) Izod specimens had a V-notch and were of standard dimensions.
Specimens (a) were held 15 minutes and (b) 10 minutes at 1725 degrees Fahr. before quenching.
A "double-slope" or nearly continuous curve was shown in most stress-strain diagrams, making difficult the determination of prop. limit. In the double-slope curves the upper limit was taken.

tion in speed of action of different individuals in hand quenching; in his tests the average velocity of specimens varied from about 3.5 to 6 feet per second for a 20-inch travel. There was also decelera-

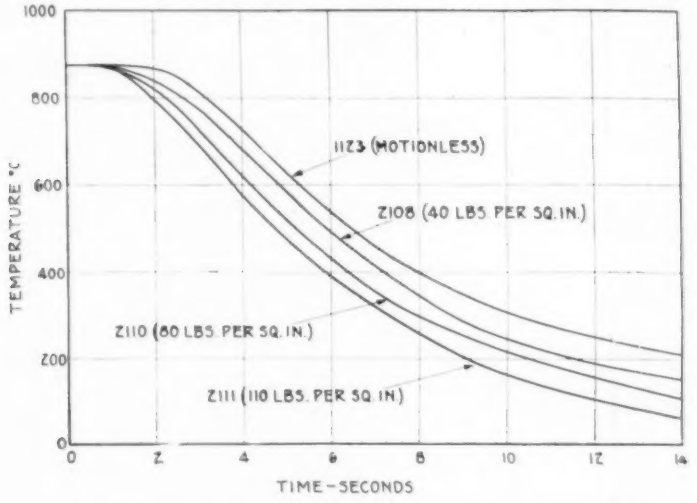


Fig. 45—Center Cooling Curves of 1-Inch Spheres Quenched in a Water Spray Under Different Pressures. Cooling in a Motionless Water Bath Given for Comparison. Coolant Temperatures 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

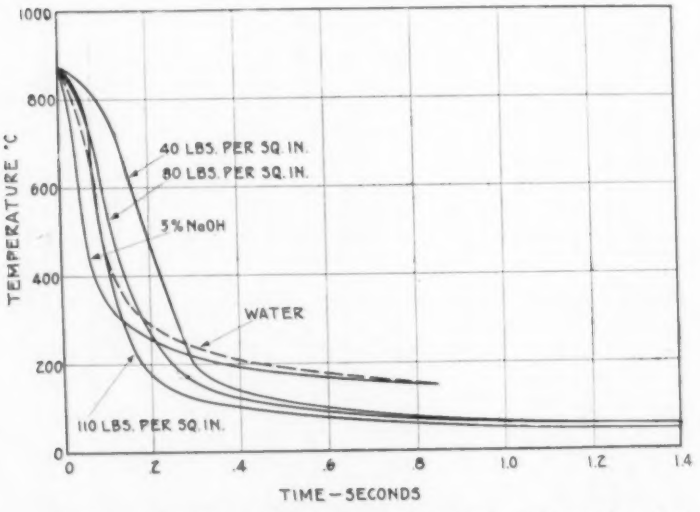


Fig. 46—Surface Cooling Curves of 1-Inch Spheres Quenched in a Water Spray Under Different Pressures. Cooling in Water and Sodium Hydroxide Baths, with Coolant Motion Approximately 3 Feet Per Second, Given for Comparison. Coolant Temperatures. 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

tion from start to finish, whereas in gravity quenching the velocity varied from close to 0 at the moment of release of the piece from the tongs to values in the neighborhood of 3 feet per second.

In most of the experiments with small specimens already described, the gravity quenching method was employed for lowering the samples into the bath at a location where the coolant was moving at approximately 3 feet per second. This method probably helped materially in reproducing the quenching conditions but the samples are known not to have cooled uniformly at different

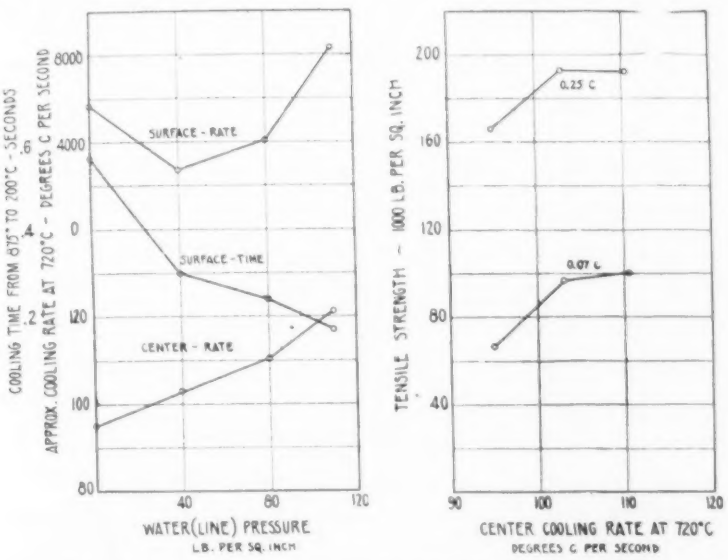


Fig. 47—Summary of Some of the Characteristics of the Cooling of 1-Inch Spheres Quenched in a Water Spray Under Different Pressures and the Relations Between Center Cooling Rates and Tensile Strengths of Low Carbon Steels.

parts of their surfaces. It is interesting to note the differences in cooling encountered in water quenching cylinders ½-inch in diameter, and to compare them with cooling in 5 per cent sodium hydroxide under corresponding conditions.

For convenience, the area which meets the direct flow of the coolant (position 1, Fig. 43) will be called the front, the area opposite this (position 3) the back, and the areas between these two, (positions 2), the sides.

In water quenching the back cooled much more slowly than the front and sides. This is perhaps, to be expected from the manner in which the liquid is conceived to flow around the cylinders under the circular motion of the coolant used in the experiments. The sides represent transition areas from the zone of most rapid cooling to the zone of slowest cooling and the manner of cooling of the sides may be expected to vary depending upon the exact condi-

Table X

Mechanical Properties of 0.25 Per Cent C Steel (Boiler Plate) Quenched in Various Ways from 885 Degrees Cent. (1625 Degrees Fahr.)

Spec. No.	How quenched	Water Line Pressure lbs. per sq. inch	Prop. Limit	Yield Point	Tensile Strength	Breaking Strength	El. in 2 inches, Per Cent	Red. Area, Per Cent	Area under stress-strain curve, square inch	Izod impact, energy absorbed foot pounds
			Lbs. per square inch							
C31-1	"As rec'd"		21,000	32,000	61,750	121,500	37.5	60.6	1.35	12, 20.5, 16 Average 16.2
C31-2	H_2O bath at 18° C.	none	25,000	.....	166,300	181,800	2.5	9.3	.71	11, 15, 31 Average 19
C31-3	H_2O spray, 17° C.	20	.....	.....	193,900	208,600	3.5	7.1	.72	11.5, 10, 16 Average 12.5
C31-4	H_2O spray, 17° C.	40	36,000	.....	192,600	241,000	6.5	17.3	1.04	
C31-5	H_2O spray, 17° C.	60	41,000[1]	.....	200,500	219,300	6.5	10.7	.70	
C31-6	H_2O spray, 17° C.	85	42,000	.....	191,400	206,000	2.5	7.8	.60	10, 18, 16 Average 14.7

[1]Double slope—upper one used.

tions encountered. In the case recorded in Fig. 43, the sides and front cooled in much the same manner but in duplicating the experiments slow cooling of the sides was sometimes observed.

The magnitude of the differences between front and back positions is shown by the fact that the front dropped to 200 degrees Cent. (390 degrees Fahr.) in about 2 seconds in water while the back required about 6 seconds to reach the same temperature. This was longer than was required when quenching in motionless water.

When translated into terms of practical heat treatment these variations in the surface cooling curves may mean variations in the hardness of the quenched product. Differences in the hardness around the circumference were observed even in the small cylinders of 0.95 per cent carbon steel used in the experiments. As is shown in Table VIII, the back was generally somewhat lower in hardness and showed more "soft spots" than the front. The sides varied, sometimes they approached the hardness of the front and at other times the hardness of the back. In some cases uniform hardness was obtained all over the surface but as indicated by many of the hardness tests and the cooling curves the described manner of circulating the coolant was not adequate to produce a uniform product regularly, when quenching in water.

A different situation was found when quenching in 5 per cent sodium hydroxide. As is shown in Fig. 43, the cooling was quite uniform from point to point around the circumference. Under the conditions of the experiments, coolant circulation was much less important in the sodium hydroxide than in the water.

It is evident from these results that sodium hydroxide is better able than water to make up for deficiencies in circulation but that circulation adequate to produce the desired hardening at the point of slowest cooling is essential in securing uniform results. More rapid flow of the coolant at one point may not be sufficient; the flow must be regulated over the entire surface.

5. *Pressure Spray Quenching*

One of the effective methods of obtaining a uniformly rapid cooling is by the use of water sprays. Very large increases in strength can be obtained in low carbon steels, which do not harden appreciably in ordinary water bath quenching, by heating the steel to high temperatures and quenching in a high pressure water

spray. Smith[18] made practical application of this method of quenching, and has been able regularly to produce bolts showing a tensile strength of over 100,000 pounds per square inch with high values of reduction of area in carbon steels containing only 0.09 to 0.15 per cent carbon.

As a further illustration of the effects of pressure spray quenching on low carbon iron alloys there are grouped in Tables IX to XII inclusive, the results of laboratory tests of 0.25 per cent and 0.07 per cent carbon steels, American ingot iron and wrought iron. Izod impact test results are given in addition to the tensile properties and in some cases comparisons are given between the results of pressure spray quenching and quenching in a bath containing 5 per cent sodium hydroxide.

A sketch of the spray used in these experiments is shown in Fig. 44. Specimens for the tensile and Izod impact tests were introduced into the quenching chamber after the spray had been turned on under the designated line pressures. Specimens used for the cooling curves were first introduced into the chamber and then suddenly subjected to the full line pressure by means of the quick opening valve (Fig. 44); the line pressure then quickly dropped to the values recorded in the individual cases. This latter procedure resulted in a variable but short interval of slow cooling at temperatures just below those at which the steels were quenched. (Figs. 45 and 46). This did not affect the comparisons in view and eliminated certain difficulties experienced when introducing specimens into the spray already under line pressures.

As is shown in Table X, the pressure spray quenching of the steel containing 0.25 per cent carbon regularly produced tensile strengths of over 190,000 pounds per square inch but the steel was quite brittle as indicated by low ductility in the tension tests and low Izod impact numbers.

Ordinary water bath quenching of steel containing 0.07 per cent carbon raised the tensile strength from a value of 47,000 pounds per square inch to 67,000 pounds per square inch. Pressure spray quenching raised the strength still further to around 95,000 to 110,000 pounds per square inch. Increased tensile strengths were also obtained in the American ingot iron and

[18] R. H. Smith: High Tensile Strengths with Low Carbon Steels, *Proceedings*, American Society for Testing Materials, Vol. 24, part II, p. 618 (1924). See also Some Physical Properties of Low Carbon Steel, TRANSACTIONS, American Society for Steel Treating, Vol. 7, No. 5, p. 569 (1925).

Table XI
Mechanical Properties of American Ingot (Armco) Iron Quenched in Various Ways from 960 Degrees Cent. (1760 Degrees Fahr.)

Spec. No.	How quenched	Water Line Pressure lbs. per sq. inch	Prop. Limit	Yield Point	Tensile Strength	Breaking Strength	El. in 2 inches, Per Cent	Red. Area, Per Cent	Area under stress-strain curve, square inch	Izod impact, energy absorbed foot pounds
			Lbs. per square inch							
AR-1	"As Received"		13,500	.....	43,700	66,100	27.5	43.7	1.19	46.5, 40, 77 Average 54.5
AR-2	H_2O bath, 20° C.	none	13,500	.....	62,100	87,300	17.5	36.4	1.37	56, 40, 47 Average 47.7
AR-5	5% NaOH bath, 20° C.	none	14,000	.....	77,300	95,900	13.5	24.2	1.15	28, 43.5, 21 Average 30.8
AR-3	H_2O bath, 18° C.	20	13,500	.....	76,800	99,300	10.0	24.8	1.30	60.5, 66, 65.5 Average 64
AR-4[1]	H_2O Bath, 17° C.	40	13,500	.....	79,800	117,500	13.5	26.2	.83	
AR-6	H_2O bath, 17° C.	85	16,500	.....	69,200	82,400	12.0	18.5	.54	63.5, 65, 62.5 Average 63.7

[1]Specimen split longitudinally at fracture.

wrought iron but the increases were of smaller magnitude (Tables XI and XII).

In the case of the ingot iron and wrought iron, quenching

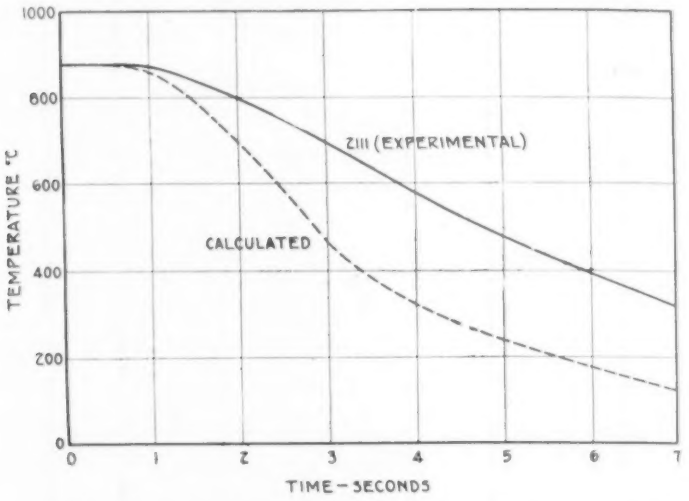


Fig. 48—Experimental Center Cooling Curve for a 1-Inch Sphere Quenched in a Water Spray Under 110 Pounds Per Square Inch Water Pressure Compared to the Cooling Curve Calculated on the Assumption of Instantaneous Drop to Coolant Temperature at the Surface. See Text for Details (First Set of Assumptions).

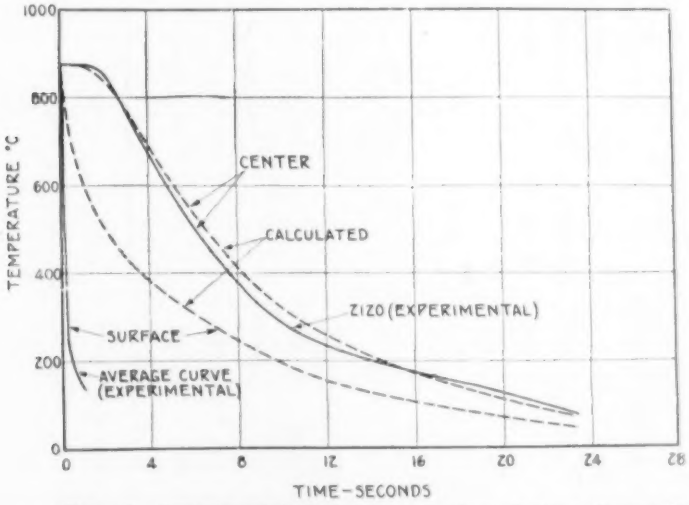


Fig. 49—Experimental Center and Surface Cooling Curves for 1-Inch Spheres Quenched in a Water Bath Compared to Cooling Curves Calculated on the Assumption of Newton's Law of Cooling. See Text for Details (Second Set of Assumptions).

in a bath containing 5 per cent sodium hydroxide produced tensile properties comparable to those produced by the pressure spray quenching in water but there appeared to be a difference in the impact values in the two cases. There are other interesting de-

Table XII

Mechanical Properties of Wrought Iron Quenched in Various Ways from 960 Degrees Cent. (1760 Degrees Fahr.)

Spec. No.	How quenched	Water Line Pressure lbs. per sq. inch	Prop. Limit	Yield Point	Tensile Strength	Breaking Strength	El. in 2 inches, Per Cent	Red. Area, Per Cent	Area under stress-strain curve, square inch	Izod impact, energy absorbed foot pounds
			Lbs. per square inch							
WI-1	"As Received"		11,000	37,250	54,500	87,200	32.0	47.5	1.79	44.5, 33.5, 46 Average 41.3
WI-2	H_2O bath, 18° C.	none	11,000	.....	56,000	88,600	24.5	44.5	1.51	41, 48.5, 50[1] Average 46.5
WI-3	H_2O spray, 18° C.	20	9,000	.....	64,000	61,500	16.0	34.2	1.09	31,[1] 73, 43 Average 49
WI-5	H_2O spray, 17° C.	85	11,000	.....	68,500	96,100	20.5	36.0	1.54	35, 47, 45.5 Average 42.5
WI-4	5% NaOH bath, 20° C.	none	11,000	.....	77,100	101,800	15.5	31.6	1.28	

[1]Large slag inclusion running longitudinally along one edge, higher reading obtained when this was parallel to direction of blow than when at right angles.

tails shown in Tables IX to XII inclusive, but from the standpoint of this investigation the important point is what relation the cooling speeds have to the large increases in tensile strength produced by the pressure spray method of quenching low carbon steels.

Time-temperature cooling curves taken at both center and surface of 1-inch spheres are reproduced in Figs. 45 and 46 while a summary of some of the important features of these curves and the relation between center cooling rates and tensile strengths of low carbon steels is given in Fig. 47.

If the variable initial periods, associated with difficulties in introducing the spheres into the pressure quench chamber, are neglected, it is seen that the speed of center cooling is very much higher with pressure spray quenching than with water bath quenching and increases generally with the line pressure.

This might lead to the conclusion that the surface cooling speeds were also much higher than in water bath quenching but examination of Figs. 46 and 47 shows that the cooling rates in the neighborhood of 700 degrees Cent. were not higher until the highest line pressure (110 pounds per square inch) was used. On the other hand, the temperature range over which rapid cooling is observed was extended to much lower temperatures in pressure spray quenching than in water bath quenching. The continued rapid cooling to low temperatures means larger temperature gradients from center to surface and the maintenance of large gradients over a greater range of center cooling than in the case of the water bath. This should reduce appreciably the center cooling times and raise the center cooling speeds in the manner shown in Fig. 45.

As has been pointed out, rapid cooling is continued to somewhat lower temperatures in 5 per cent sodium hydroxide than in water baths. Rapid cooling continued to even lower temperatures in the case of the pressure spray and through the increased speeds of cooling at the interior of the body produced the high strengths shown in Fig. 47. However, the tensile strength is probably not solely a function of the cooling rates since with increase from 80 to 110 pounds per square inch water line pressure the rates of cooling increased at the center and the cooling times decreased but the changes in the strength of both the 0.07 and 0.25 per cent carbon steels were very small.

VI. Comparison of Experimental and Derived Cooling Curves[19]

The problem of determining the temperature at any point in a body as a function of time, under a given set of conditions, is one which is sometimes capable of solution mathematically. It is a

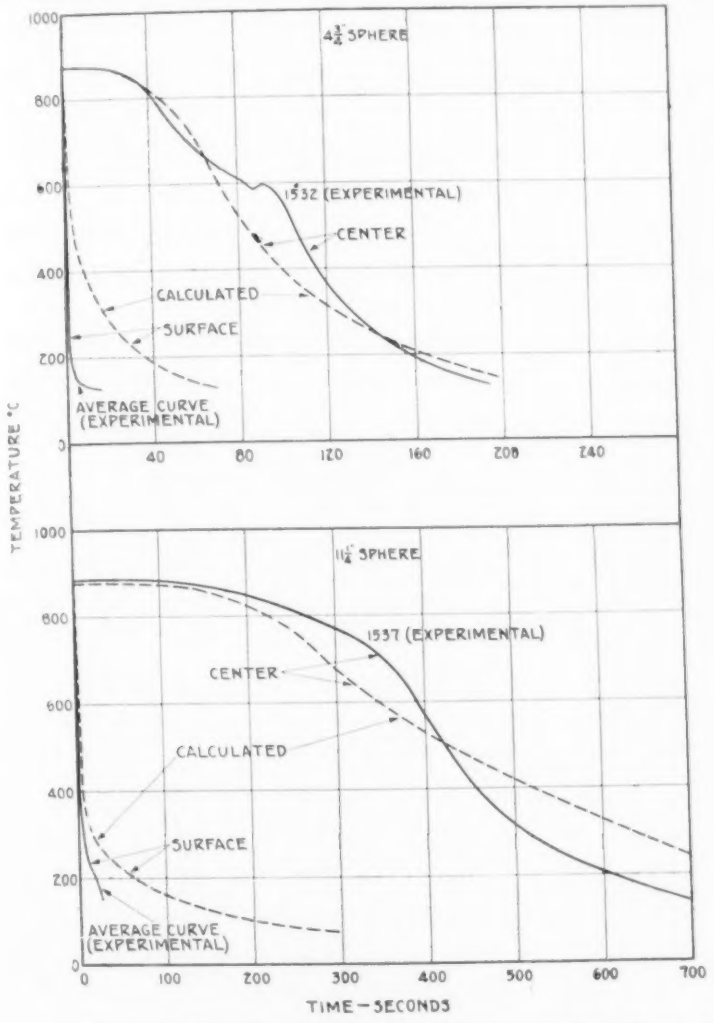


Fig. 50—Experimental Center and Surface Cooling Curves for 4¾ and 11¼-Inch Spheres Quenched in a Water Bath Compared to Cooling Curves Calculated on the Assumption of Newton's Law of Cooling. See Text for Details (Second Set of Assumptions).

matter of some interest to determine if these mathematical treatments can be applied to the practical problem of temperature distribution during quenching.

The process of solving such problems is one of finding a solu-

[19]The computations used in the discussion in this part of the paper were made wholly by Dr. Cook.

tion of the general differential equation of heat conduction which fits a set of "boundary conditions" determined by the problem under consideration. There are two well known solutions which are based on assumptions which should give a fair approximation to the facts. Both of these will be discussed in the following paragraphs.

The general differential equation is

$$\frac{du}{dt} \alpha^2 \left(\frac{d^2u}{dx^2} + \frac{d^2u}{dy^2} + \frac{d^2u}{dz^2} \right)$$

Here u is the temperature, t, the time, and x, y and z the space coordinates; a^2 is the diffusivity of the material and is defined as $\frac{\lambda}{sd}$ where λ is the thermal conductivity, s. the specific heat, and d, the density.

The diffusivity is assumed constant although it is known to be a function of temperature. Futhermore, there is little information available on the values of diffusivity for steels over the range 20 to 875 degrees Cent. (65 to 1605 degrees Fahr.), as has already been pointed out. It is likewise, assumed that there is no heat developed within the material which means that the heats of transformations are neglected, but this should lead to serious errors only in cases where large heat effects are observed. The heats of transformations can be neglected when cooling small pieces rapidly.

The first of the solutions of the general equation of heat conduction assumes the following "boundary conditions"; the temperature of the body is uniform at the time of quenching and the surface temperature falls instantly to the temperature of the coolant. As seen from the experiments already described, this latter assumption is a good approximation only in the case of the most drastic coolants such as pressure spray quenching or for bodies of low diffusivity.

Fig. 48 shows a cooling curve for the center of a 1-inch sphere computed on these assumptions, compared to the experimental curve obtained in the drastic pressure spray quenching. The value of diffusivity used in the calculations was 0.07 cm.^{2} sec.$^{-1}$, and is assumed to be a fair average value over the entire cooling range. This value gives a computed cooling curve which is much faster than the experimental curve. Lower values of diffusivity would

bring the two curves closer together but such lower values do not seem justified in the light of present information.

The second solution mentioned above, assumed that the surface of the body loses heat at a rate proportional to the difference in temperature of the surface and the coolant. The proportionality constant is called surface conductivity and depends upon the coolant and probably also many other factors. It does not seem reasonable that so simple a law should hold for cooling in liquids[20] where the range of temperature is so large as in the quenching of steels but the surface temperature curves computed on this assumption have the same general characteristics as the experimental curves.

The results of such calculations are shown in Figs. 49 and 50. A value of surface conductivity (1.18 cm^{-1}) was chosen which gave a good approximation to the experimental results for the center of the 1-inch sphere and this value was then used in computing the center and surface temperatures of the 4¾ inch and 11¼ inch spheres. The derived and experimental center cooling curves show fairly good agreement but the surface curves are very different for the 1-inch sphere. However, the experimental and derived surface curves show closer agreement as the size of sphere is increased.

A possible explanation of the differences between the computed and experimental cooling curves is that the experimental curves represent cooling over only a small area of the surface. Certain portions of the surface may cool very slowly at first as shown by "hot spots" which have been observed to remain subsequent to the introduction of the sample into the coolant. These would make the average temperature of the whole surface somewhat higher than the temperatures observed experimentally at one location. If it were practicable to take account of these effects, the experimental and computed cooling curves might be brought closer together.

The liberation of heat during transformations is another factor which has been neglected in the computations and which tends to increase the differences between the computed and experimental

[20]The experiments of H. Worthington and C. B. Malone, Convection of Heat from Small Wires in Water, *Journal*, Franklin Institute, Vol. 184 p. 115, (1917), indicate that the rate of dissipation of heat probably does not increase proportionally with rise in temperature of the body immersed in the liquid. The rate of increase of dissipation is faster than this law would indicate.

cooling curves. The surface areas pass through the transformation temperatures before the interior and conditions may be encountered where the heat of transformations from the surface metal will retard the center cooling before the center has reached the transformation temperature range. Examination of the experimental cooling curves shows that the cooling rates are not very different from the calculated values but there is an initial lag which is greater for the larger sizes.

Evidently such calculations as have been described are of limited practical value. More accurate predictions would require a more accurate knowledge of the true laws of cooling and must also take into account the heat of transformations. The computations based on the simple assumptions already stated are extremely tedious but may be made quite simply with the aid of tables computed by Gröber.[21]

VII. Summary

1. An experimental study was made of surface cooling of steel spheres varying from ¼ to 11¼ inches in diameter. The methods of test employed are recognized to have given only approximate determinations of surface temperatures but they have been shown to give information consistent with practical experiences. The surface cooling velocities in the neighborhood of 700 degrees Cent. (1290 degrees Fahr.) varied from about 12,000 to 3000 degrees Cent. per second in 5 per cent sodium hydroxide, from 8000 to 1000 degrees Cent. per second in tap water, and under 600 degrees Cent. per second in a commercial quenching oil when the coolant motion was in the neighborhood of 3 feet per second.

2. Under the slow flow of the coolant in the experiments, the cooling at any particular point was not necessarily continuous, but was the resultant of a large number of temperature fluctuations throughout a part of the cooling range. These fluctuations were more marked when quenching in water and 5 per cent sodium hydroxide than when quenching in oil and are considered to be the result of rapid repetitions of a cycle of gas formation at the surfaces of the heated metal and its removal by the liquid coolant. The results clearly indicated the desirability of adequate circula-

[21] H. Gröber: Die Erwärmung und Abkühlung einfacher geometrischer Körper, Zeit. d. Ver. Deutscher Ingenieure, Vol. 69, p. 705 (1925).

tion of the coolant for the production of uniformly hardened steels.

3. Cooling was retarded by factors which tended to promote adherence of gas at the metal surfaces, such as loosely adherent scale, roughened surfaces and large amounts of gas dissolved in the coolant. Water saturated with carbon dioxide at atmospheric temperatures and pressures cooled the steel more slowly than water saturated with air which in turn cooled the steel more slowly than water saturated with oxygen. In the latter case, the cooling was about the same as that in Washington city (tap) water and boiled water.

4. Adherent oxide was effective in decreasing the speeds of cooling. Scale which was readily blown off by gas evolution in aqueous solutions did not seem to affect the cooling appreciably. All oxide coatings became of more importance in less drastic media, such as oils, in which the conditions tended to preserve the continuity of the oxide envelopes.

5. The surfaces of small spheres heated in salt and quenched in tap water cooled as rapidly as the surfaces of similar spheres heated in air and quenched in sodium or calcium brines. This was considered to be due to the avoidance of oxidation in heating and the solution of adhering salt by the coolant in quenching.

6. Experiments with chromium plated, nickel plated and unplated steel spheres quenched in mixtures of pale neutral and heavy residuum oils indicated that the relation between the metal surface and the coolant is of importance. Small additions of the residuum oil to the pale neutral oil increased the speeds of cooling at high temperatures in the unplated specimens. The increases were smaller in the chromium plated specimens and practically absent in the nickel plated steels.

7. Adherent scale, roughness of surface, gases formed by or released from the coolant and inadequate coolant circulation, each tended to promote unstable conditions in quenching and lack of uniformity in hardening.

8. The high tensile strengths produced in low carbon steels by pressure spray quenching with water were associated with very high rates of center cooling. The surface cooling speeds at high temperatures were not necessarily higher than those obtained in water bath quenching but the rapid cooling continued to lower temperatures.

9. Pressure spray quenching with water produced more nearly an instantaneous drop of the surface to coolant temperatures than did a 5 per cent sodium hydroxide bath. Likewise, the rapid surface cooling continued to lower temperatures in sodium hydroxide than in a water bath.

10. Increases in size of sphere produced relatively small increases in the time required for the surface temperature to drop from the quenching temperature of 875 to 600 degrees Cent. (1605 to 1110 degrees Fahr.), in any one of the coolants, oil, water, 5 per cent sodium hydroxide, or air. However, the increases were larger in the slow coolants, oil and air, than in the rapid coolants, water and 5 per cent sodium hydroxide.

11. For large cooling ranges, such as 875 to 200 degrees Cent. (1605 to 390 degrees Fahr.), the cooling times increased more rapidly with size in water than in 5 per cent sodium hydroxide or air. However, the largest increases were obtained in oil.

12. Experimental center and surface cooling curves were compared with curves derived from two different sets of assumptions. Agreement was obtained by proper choice of constants for one size of sphere but with one set of constants, agreement could not be obtained over the entire range of sizes studied. Possible reasons for the differences are discussed in the report.

DISCUSSION

Written Discussion: By J. L. Cox, Midvale Company, Nicetown, Philadelphia.

The thanks of the society are due Mr. French and his associates for the elaborate report they have just made on "The Surface Cooling of Steels in Quenching". Although practical application of many of their conclusions has long been made by those in the business of hardening steel, they have discovered some new and very interesting facts. Then, too, it is highly satisfactory to have quantitative measurements of the phenomena, even though the measures be admittedly only approximately accurate. The nature of the case forbids much more, because as it is a common sight, on quenching, for large objects to show spots visibly red for an appreciable time after immersion, it is evident that no accurate cooling rate can be established there for such conditions and presumably a proportionate irregularity of cooling exists in all cases.

Unless it had been measured, I think no one who saw a piece of steel quenched could imagine that the rate at which the surface temperature may drop could reach 8000 degrees per second; nor would one have any

adequate idea of the possible magnitude of the effect of gases, particularly carbon dioxide, in the quenching medium.

That size has little effect on superficial rates of cooling as compared with its effect on center cooling rates might be imagined because of the dependence of the latter so largely on the conductivity coefficient of the steel. It is well illustrated by such objects as the heads of armor-piercing projectiles, which, irrespective of caliber, quench to essentially alike sclero-scope figures, although the interior of the head grows progressively softer toward the center at a fairly uniform rate per inch.

The gaseous envelope released by the coolant, or produced from it, may be fairly effectively removed and a supply of fresh coolant provided by motion of the object or of the coolant, as in the majority of the authors' experiments, but far more effectively by a spray, as described toward the end of the paper. Roughness of the surface, shown to increase the cooling time in ordinary quenching, can figure but little in spray quenching.

As long ago as 1892, Henri Aimee Brustlein, inventor of the steel armor-piercing projectile, stated that chromium steel could only be hardened properly in a spray, and the device has been in constant use since then.

The authors state that Smith, in 1924, was one of the first to secure very great increase in the strength of low carbon steels by spray quenching, but in 1915 the French Government used the method for vast numbers of medium carbon high explosive shells. Medium carbon steel, having an annealed tensile strength of from 78,000 to 92,000 pounds per square inch, by spray hardening was raised to from 121,000 to 149,000 pounds per square inch. Figures as high as 147,000 pounds tensile strength, 135,900 pounds yield point, 10.4 per cent extension in 3.9 inches and 43.8 per cent contraction of area were obtained after hardening and tempering a steel containing 0.33 per cent carbon and 0.64 per cent manganese.

As a spray cannot always be used, it is of much interest to note that a 5 per cent caustic soda solution will accomplish approximately as rapid cooling under favorable conditions.

The effect of scale upon surface hardening has necessitated much study but is now fairly well understood. As the authors state, if the scale be thin, uniform and adherent, cooling will be delayed. The piece, then, may or may not harden fully, depending on its composition, but the surface will be of uniform hardness. Blisters should be carefully avoided. If present they will generally break in water, but it is much safer to knock them off before quenching because, if they do not break, the steel beneath them will be very soft. A surface partly covered by thin adherent scale and partly exposed by broken blisters, will harden most unevenly in a carbon steel, while in a chromium steel there may be no observable hardness difference, the latter steel hardening so much more energetically. This lack of energetic hardening requires a spray for carbon steel to be much more accurately made than one for the alloy steel. A spacing of holes that may answer satisfactorily for the alloy steel will produce spotty hardening of carbon steel.

Where it can be used, the authors' work shows clearly the advantages of heating for hardening in a salt bath, which heats much more rapidly than a furnace and protects the piece from oxidation both while heating and in transit to the quenching bath.

A point mentioned by the authors but not investigated, although of possible great practical interest, is the effect of temperature of coolant upon the rate of cooling. It is to be hoped that some day they will report upon it.

We do not altogether agree with the authors' observation that the 2½ inch sphere quenched in water cooled more quickly than the 1 inch and it in turn more quickly than the ½ inch, because although this was true in individual instances it was not so on the average.

In conclusion the contribution is one which represents a vast amount of work and contains valuable information for which we offer our personal thanks to the authors.

Written Discussion: By F. R. Palmer, Carpenter Steel Co., Reading, Pa.

It is a pleasure to read a thorough and comprehensive paper such as these authors have presented. This and previous papers presented by Mr. French on the subject of quenching cover a type of work which no industrial laboratory would be likely to attempt and yet the data is extremely important because of its practical application.

A terrific strain is being thrown on our present tool steels by the demand of modern high-pressure production. Although new alloys and new treatments are constantly being developed to cope with this situation, it has been the writer's opinion for some time that there are enormous untouched possibilities in regulated quenching of the tool steels which we already have. Papers like this advance the time when scientific quenching may come into its own in our hardening rooms.

The statements contained on page 250 regarding the effect of various atmospheres are most interesting. We often hear it said that "heat is heat" and the source does not greatly matter. This is contrary to the experience of almost every practical hardener and the authors of this paper suggest that the answer may be found in the type of scale which results from the heat, and the effect of this scale on the speed of quenching. The writer has occasionally seen extreme cases where a piece of tool steel would not become hard when heated by radiant heat and quenched in oil, but would become file-hard when quenched in oil from the same temperature secured in a coke-fired furnace forge.

It is to be hoped that the authors will continue to make available data of this nature.

Written Discussion: By P. E. McKinney, Naval Gun Factory, Washington, D. C.

1. The subject covered by this very interesting paper is of considerable importance not only as a scientific study but also from the standpoint of its direct applicability to practical heat treatment problems.

2. In considering the subject of surface cooling phenomena we must necessarily also consider the question of center cooling of masses as presented in previous works by French and Klopsch.

3. The methods adopted for determining surface cooling are quite ingenious and are probably as free from variables as is possible under the circumstances.

4. There are, however, several factors in connection with the accuracy of these results which might be given consideration at this time. In the first place, the spheres which were used varied in composition between the smaller size and the larger size spheres. With the known differences in diffusivity one variable is introduced on this account. Of greater significance regarding the introduction of variables as between sizes is the question of cooling effect through the transformation range. It is rather definitely known that in masses the retardation of cooling at the transformation point is quite considerable and is protracted, varying in this respect with the mass involved as well as with the rate of heating and cooling. The variable introduced from both of the above factors could probably be overcome by the use as a check of spheres made from alloys having approximately the same diffusivity as steel, accepting for this purpose one of nickel alloys not subject to any transformation at the normal critical temperatures of steel.

5. The results of the work performed by the authors would indicate that three important factors among others control the surface cooling of the steels:

A. The diffusivity of the steel
B. The heat conductivity of the quenching media
C. The surface condition of the steel.

6. Referring to diffusivity of the steel, while at first glance it might not appear that this is an important factor on account of the relatively small difference between the diffusivity of the various grades of steel, it should be remembered that the rate of temperature change while passing through the transformation range has a marked influence on the hardness of the steel a great deal more so than would be indicated by the small difference in this characteristic of steels of different composition. The diffusivity of the steel itself must necessarily be very closely tied up with the heat conductivity of the quenching media, as the removal of heat from the surface can only be compensated for by a sufficiently rapid movement of heat from the center of the mass. These two factors are again closely tied up with the surface condition of the specimen which contacts between the two bodies, namely, the steel and the quenching media.

7. Table VI indicates clearly the influence of surface condition on the rate of surface cooling. This would indicate rather conclusively that any foreign coatings whatsoever act as a retarding or insulating agent between the steel and the coolant. The oxidized surface or carbon coated surfaces retard surface cooling to a marked extent, the electroplated surface even more so, whereas the specimen heated in a salt bath showed a marked increase in cooling rate at the surface.

8. It is quite natural to expect that the coatings of foreign material should slow down the cooling rate proportionate to the insulating effect afforded by the coating and its effect on the properties of the coolant to establish the closest and most intimate contact with the surface of the metal. This will apply equally in the case of all coolants although the effect of scale or foreign matter on the surface of the material will vary depending on the repulsive action set up by these coatings and the intimate contact between the metal and the coolant.

9. Closely associated with these surface conditions is a tendency of some of these insulating surfaces to increase the tendency for gas expulsion from the coolant in close proximity to the steel. These liberated areas of gas act as a further insulating agent to retard surface cooling.

10. It is believed that if the experiments which were reported in this paper on quenching in water highly saturated with carbonic acid were carried out on the same scale with materials coated by various methods a very marked difference in the behavior of the liberated gas would be found on various specimens.

11. In the case of electroplated material there is a ready explanation for the marked difference in cooling rate between chromium plated and nickel plated specimens which probably are in no way tied up with the conductivity of the electroplated surfaces but probably is due more to the well known characteristic of nickel plated surfaces to lose close adhesion to the basic metal on heating setting up a minute air space under the plated surface. This characteristic does not exist in the case of chromium plated steel.

12. The very rapid rate of surface cooling in the case of specimens heated in salt is probably not due to the change of composition of solution due to the solutions of the adhering salt but rather due to the fact that on the solutions of the salt the liquid is permitted to so closely contact with the surface of the steel without the liberation of gases. The contact between the liquid and the metal is perfect and the full benefit of the diffusivity of the material and conductivity of the coolant are taken advantage of.

13. It is believed that this paper should be considered as one of a series of papers to be followed by the results of further work on this extremely interesting subject as it is believed that it has the closest connection with the practical problems of heat treating heavy masses not only for surface effect but for effect through the entire mass.

14. It is believed that a comparison of surface cooling effect should not only involve water and oil but should be checked against metallic media such as mercury and the emulsions of oil and water.

THE MANUFACTURE OF ACID OPEN-HEARTH STEEL FOR FORGING INGOTS

By H. P. Rassbach

Abstract

Recent demand for heavy forgings requiring high physical properties is outlined briefly. New developments in testing methods are mentioned. Reasons are given for the selection of acid open-hearth steel for heavy forgings.

Suitable charges for the acid furnace are discussed. The operation of the heat is discussed and reasons are given for the various procedures. Special emphasis is placed on the desired condition of the bath and slag in the different stages of the heat. Fundamental slag reactions are discussed.

Various methods of pouring are compared. It is emphasized that composition, size of ingot, and use for which it is intended are the factors that determine the method to be employed. The casting of a 420,000-pound ingot is described.

DURING the last five years various industries have made unusual demands upon the steel manufacturer. Forgings requiring ingots weighing over two hundred tons are now not uncommon. The steel producer is continually being called upon to furnish larger and larger forgings and at the same time produce steel which is capable of withstanding searching tests and showing high physical properties at high temperatures, etc.

It might be of interest to mention a few of these new developments in engineering design. The oil industry is requiring "cracking" chambers of unusual size. Some of them consist of a hollow-forged cylinder 78 inches inside diameter, 4 to 6-inch wall thickness and 40 feet overall length. Beside tensile test requirements, these cylinders must undergo a hydrostatic test of 3000 pounds per square inch. The actual weight of many of these forgings is as high as 300,000 pounds.

A paper presented before the tenth annual convention of the society, held in Philadelphia, October 8 to 12, 1928. The author, H. P. Rassbach, is connected with the open-hearth department, Midvale Co., Philadelphia. Manuscript received July 30, 1928.

The chemical industry has called for forgings of alloy steels nearly as large as the ones furnished the oil producers. This has made necessary the casting of large ingots of sensitive alloy steels. Great care must be exercised in handling them. The successful manufacture of forgings from such large masses of alloy steel also constitutes a very difficult problem for the forge. Much costly experience is necessary to determine the care which must be taken at all times.

The recent trend in power plant design in the construction of large turbine units has resulted in the manufacture of very large forgings of the highest quality steel.[1] The unusual operating stresses placed upon such parts as turbine shafts, turbine wheels, rotors and spindles make these severe tests necessary. Steam pressures of 600 to 1400 pounds on some modern boilers have required large drums capable of withstanding these stresses.

The increasing thoroughness of modern testing methods during the last few years has been very noticeable. Both transverse and longitudinal test requirements are not uncommon. Some customers demand etch tests. In some cases the microstructure is examined for homogeneity. The practice of boring forgings and examining the bore for defects is now common. Some forgings must be submitted to a magnetic test which will indicate the presence of large nonmetallic inclusions and discontinuities in the metal. The increasing severity and thoroughness of testing methods make the production of high quality steel essential for a large number of products.

The large amount of capital invested in a single unit in the production of heavy work of the type mentioned makes it necessary to decide which of the two common methods of steel making will give the better results. It has been the experience at the Midvale Company that the acid open-hearth is superior for such duty. Long experience with both acid and basic steel has shown that consistently better results may be achieved with the acid process. The uncertainty of transverse tension tests taken from basic steel has led to our practice of always using acid open-hearth steel in cases where such tests are required. In the case of all large and intricate forgings the financial loss due to failure is so great that the

[1]The terms "high grade" or "quality" when used in this paper will describe a steel which has been produced with the utmost care and can be successfully submitted to both longitudinal and transverse tension tests more than ordinarily severe.

manufacturer is compelled to choose the safer method for producing the steel.

There is no intention of implying that all acid steel is more sound and cleaner than basic steel. Poor steel can be made by either process. However, it will be pointed out, that by employing sound practice it is probable that consistently better results may be achieved by the acid process. The chief reason why this is true is probably due to the fact that the acid process is fundamentally less complicated than the basic process. It is my purpose to point out some of the advantages of the acid open-hearth for the production of steel in the furnace containing a minimum amount of oxides. It will be shown how the practice employed is in accordance with some of the fundamental laws of physical chemistry in achieving this end. A detailed discussion of slag-metal reactions must be omitted because of lack of reliable data. Dr. C. H. Herty, Jr., in a paper entitled "Fundamental Research In Steel Manufacture," has outlined the great number of problems which must be solved before any exact predictions can be made concerning these reactions.

The practice described in this paper is employed by the Midvale Company. The furnaces used vary in capacity from 50 to 70 tons and are fired with fuel oil. There will be no discussion of furnace design, as this would require a paper in itself.

Operation of the Acid Open-Hearth Furnace

The Charge—Phosphorus and sulphur are not removed in the acid open-hearth, therefore the materials charged must contain a smaller percentage of these elements than is permitted in the finished product. Allowance must be made for an increase of sulphur from the fuel. Producer gas and the grades of oil commonly used are sufficiently high in sulphur to cause an appreciable gain of this element in the metal.

The carbon content of the charge should be sufficiently high to allow the heat to melt down with a carbon content considerably above that specified in the final product. This is of the utmost importance in the process. If a heat melts down low in carbon, namely, near the required point or below it, only one course is open, the heat must be "pigged back". In other words, pig iron or spiegel must be added in large quantities to bring the carbon

content up to a point sufficiently high to allow proper working of the heat. This is a poor practice, involving great expense in the time lost.

It is very desirable to have an appreciable amount of manganese and silicon present in the original charge. The formation of MnO and SiO_2 are exothermic, thus their oxidation aids melting. Furthermore, these reactions, being exothermic, proceed at lower temperatures than the reaction for carbon elimination, which is endothermic, and, therefore, favored by high temperatures. Any manganese and silicon not oxidized during melting will reduce iron oxide formed during the melting period. Thus it is possible to have a fairly good slag on the bath almost as soon as it is melted. One might say that the chief role of manganese and silicon in the original charge is a safeguard for the carbon. The presence of sufficient manganese and silicon in the original charge helps to insure the heat in melting down high in carbon.

The scrap should not be too light or fine. The smaller the scrap the more oxide will be formed while melting. Iron oxide in too large amounts will cut the bottom and choke the checkers. It will also have the same effect as an overdose of ore in making the operation of the heat uncertain. Aside from chemical composition and physical characteristics, it is very improbable that any other properties of the scrap could have any effect on the final product. Some authors have suggested that the superiority of acid steel over basic steel might be due to the fact that the raw materials used, being necessarily lower in phosphorus and sulphur, are inherently better than the materials used in the normal basic charge. This statement is very questionable. We have been unable to find any evidence substantiating this argument.

Operation of the Heat—The charge after being thoroughly melted should be given time in which to increase its temperature before any ore additions are made. The slag should also be noticed at this point. If excessively dark, time should be allowed for it to become lighter in color. A black slag indicates a high percentage of iron oxide present, thus the condition of the heat in respect to carbon is uncertain when covered by such a slag. Small additions of limestone are effective at this point in improving the condition of the slag. The lime will act as a flux, making the slag more fluid. The addition of this basic oxide will tend to replace iron oxide from the slag into the metal. Thus the reduction

of excess iron oxide is hastened by this addition. It must be understood that the slag condition at this point is not a fixed standard, but is one to be set by each melter for himself, depending on the grade of steel he is making.

After the bath is hot and a fracture test has been made which will serve to indicate roughly the percentage of carbon present, iron ore may be introduced into the furnace. The addition of the proper amount of ore requires judgment acquired only through experience. If too much ore is added the carbon will come too low, necessitating additions of pig iron. Furthermore, it will be likely that the final product will contain a large amount of oxide inclusions, due to the excessive amount of iron oxide in the bath. The addition of the proper amount of ore will result in the carbon being eliminated rather quickly to a point slightly above that desired to "go ahead" on. There should be opportunity to slowly approach the desired point and clear the bath and slag of excess iron oxide. The term "slowly" used in this connection is purely relative. The speed of carbon elimination varies greatly with the grade of steel. It will be found at this stage of the heat that the bath will be increasing in its silicon content, if properly handled. This phenomenon is very marked in its appearance. The fairly violent boil of the oreing period is replaced by a slag surface practically flat, having occasional bubbles coming through it. The gradual increase of the silicon content of the bath can also be seen easily by pouring tests. This phenomenon has been commonly designated as "condition". It is obvious that the possibility of reaching this condition depends chiefly on the skill of the melter in adding the proper amounts of ore at the proper times. Other factors involved will be discussed later.

It has been found by experience that the production of high grade steel without reaching this condition is very questionable. It has been proved sound practice always to get a heat into condition before any final additions are made to the bath. This phenomenon is the reason why the production of sound acid open-hearth steel is much simpler than the production of equally sound basic steel. There is no indication in the working of a basic heat so marked as the one just described. Regardless how expert the melter may be, it is logical to expect more consistent results in the case where he has unmistakeable signs to guide him to the right path.

When the fracture tests indicate that the heat is approaching the desired percentage of carbon, a test is sent to the laboratory. If the carbon reported on this test is the correct amount needed to have the heat finish to the specification, silicon in the form of ferrosilicon is added. This addition has the effect of preventing further oxidation of the carbon. The amount of silicon added will be rather small in most cases because the bath will have acquired an appreciable amount from the slag by this time. Another test may be sent to the laboratory prior to adding the ferrosilicon to serve as a further check on the carbon. In some cases it is necessary and in others it is not, depending on how near the carbon was to that desired on the "go ahead" test.

The addition of the ferrosilicon at the proper time is of great importance. If added too early, time will be lost, because the carbon content will be too high. Adding ore at this time to speed up the removal of carbon will ruin the condition of the bath. On the other hand, time will be lost in allowing the carbon to come down without ore. If the ferrosilicon is added too late, namely, when the carbon content is lower than that required, it will be necessary to add pig iron to raise the carbon up to the point desired. It has been proven beyond a doubt with quality steels that excessively large additions of this nature have a very bad effect on the grade of the steel produced. It would be very difficult to describe specifically what effect such additions could have on a heat which is practically in equilibrium, however, it has been proved without a doubt that the result is inferior steel. In some cases it has been deemed more advisable to make a stock heat with lower carbon content without adding pig iron than to add the large quantity of pig iron necessary to have the heat finish as specified. In other cases a very large amount of pig iron was added and the process of making the heat was started from the beginning again.

There is no set rule for making the addition of finals, such as ferromanganese, ferrochromium, etc., except that the heat must be in condition. It is the best practice to introduce the alloys as early as possible without unduly risking a large loss. Ferrochromium is generally added after the ferrosilicon and before the ferromanganese. The ferromanganese is held at least 15 minutes before tapping. It may be held longer, depending on the amount added.

Except in rare cases, ladle additions are not made. It is

obvious that they are undesirable because of the uncertainty of forecasting what conditions may be established by their presence at this point. The fact that practically any grade of steel may be made entirely in the furnace is one of the advantages of the acid open-hearth process. It is an opportunity which should be taken advantage of whenever possible.

The addition of aluminum or other violent deoxidizers or degasifiers are not necessary in the production of sound acid steel. They are not used in steel which has to meet high transverse requirements. As the baneful effect of aluminum is well established and is unnecessary in the production of sound acid open-hearth steel, there is no valid reason to justify its use in the production of high grade steel.

The Acid Open-Hearth Slag—The slag in the open-hearth furnace consists chiefly of the three oxides, SiO_2, MnO and FeO. There may be small quantities of other oxides, such as Fe_2O_3, CaO, Cr_2O_3, and Al_2O_3 present. The MnO content of the slag will depend on the amount of manganese present in the original charge. In the acid process both manganese and silicon are practically eliminated from the bath within a short time after the bath is melted. The FeO content of the slag, when the charge is first melted, is generally rather high, due to the large amount of oxides formed while melting. As soon as the bath becomes hot this condition is improved by the reduction of FeO by carbon. This change can be easily recognized in the appearance of the slag. It will change in color from a black or dirty brown to a bluish yellow, yellow or white, depending on the amount of FeO and MnO present. A light colored slag is always comparatively low in FeO. It can also be stated in general that the slag will be light in color when "condition" has been attained. The changes in appearance of the slag throughout the heat serve as a dependable guide for the melter.

Iron oxide, FeO, is the oxidizing agent which accomplishes the removal of carbon, manganese and silicon. The removal of carbon from the bath is represented by the equation:

$$FeO + C \rightleftarrows Fe + CO$$

The presence of small amounts of Fe_2O_3 in the slag may be explained by the oxidizing effect of the flame on the FeO in the slag.

$$4\ FeO + O_2 \rightleftarrows 2Fe_2O_3$$

This Fe_2O_3 is, in turn, reduced to FeO at the slag-metal surface by the following equation:

$$Fe_2O_3 + Fe \rightleftarrows 3FeO$$

A small amount of FeO is also formed by direct oxidation of small particles of steel suspended in the slag during the boil. FeO is soluble in iron. The amount of FeO present in steel of a certain composition, at a certain temperature covered by a slag of a certain composition is proportional to the FeO content of the slag. This is an expression of Nernst's law of distribution. There will be a certain coefficient of distribution for each set of conditions. If temperature and slag composition are not greatly altered it is reasonable to expect that the amount of FeO dissolved in the bath will be proportional to the amount of FeO in the slag and the carbon content of the bath.

The rate of carbon oxidation at a given temperature will be proportional to the amount of FeO and carbon present. This is an application of the law of mass action. Let us now take the case of a heat that has had the proper amount of ore added and is now slowly approaching the desired point in carbon content. No more FeO is added in the form of iron oxide. As oxidation of the carbon proceeds, more and more oxygen is required. Finally the oxide in the bath will approach a condition of equilibrium with the carbon. (For certain temperature and slag composition.) These points are very effectively brought out in Bulletin 34 of the U. S. Bureau of Mines on the subject of "The Physical Chemistry of Steel Making".

By bringing the heat slowly to the desired point in carbon, this equilibrium may be approached, resulting in a minimum FeO content in the bath. A limiting factor in the percentage of FeO that may be eliminated in this manner is the oxidizing flame. It is continually adding oxygen to the slag.

When this point in the heat has been reached, namely, when the slag has become light in color and the carbon oxidation has reduced in speed, the bath will begin to pick up silicon from the slag, if high temperatures are maintained. It was mentioned before that the appearance of the bath at this period is flat and practically motionless compared with the boiling of the oxidizing

period. There seems to be considerable controversy in regard to the method by which silicon is reduced. Two equations which have been suggested are:

$$SiO_2 + 2C \rightleftarrows Si + 2CO \quad (1)$$
$$SiO_2 + Fe \rightleftarrows FeSi + O_2 \quad (2)$$

Equation (1) has probably been suggested because in practice it has been found that the ease with which silicon may be reduced is proportional to the amount of carbon present. It is very difficult to pick up silicon in a very low carbon heat. It has also been found that a high temperature is necessary.

Equation (2) was suggested by Yaneske and Wood before the British Iron and Steel Institute in 1920. They claim that iron, being present always in great excess, must be a far more powerful reducing agent than carbon. They have no concrete data to justify their assumption. It would be very interesting to know the correct explanation of this reaction. It is probable that slag-metal reactions are far too complex to describe with simple equations.

Regardless of the method by which silicon is reduced, the matter of greatest importance is that it is reduced. Neither is the amount reduced of great importance. It can be stated that the presence of silicon in a bath of metal will decrease the amount of oxides present. Conversely it may be assumed that a large amount of oxides present would not allow an appreciable amount of silicon to be maintained in the bath. Thus it may be believed that "condition" or the phenomenon of picking up silicon cannot take place until the bath is fairly well deoxidized. This belief has led to the practice. The less deoxidizing the deoxidizers have to perform, the better are the chances of obtaining a clean product. It has been proven that heats that have had large losses in silicon and manganese over the amount added, are generally dirty. The fact that an acid heat can be practically deoxidized before any final additions are made, is very probably the reason why acid steel can be made cleaner than basic steel. The fact that the recovery of ferroalloy additions made to a properly handled acid heat is very high, serves to substantiate the belief that the heat is well deoxidized.

Due to the oxidizing effect of the flame the acid slag can never become actually reducing, but it can be made to approach the neutral condition. It is probable that a considerable part of the

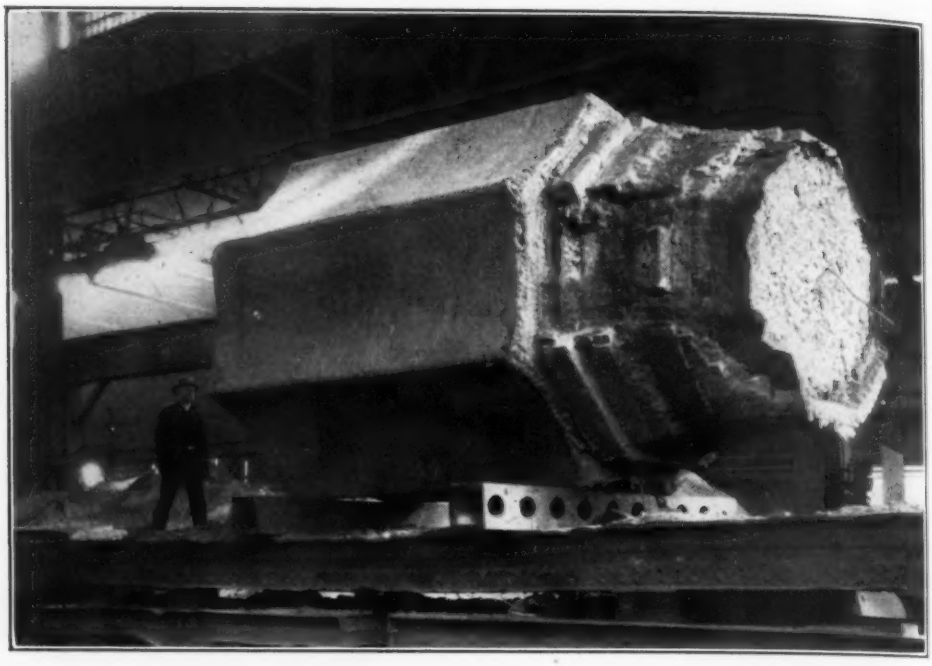


Fig. 1—Photograph Showing an Octagon Ingot Weighing 400,000 Pounds and Having a Diameter of 108 Inches.

FeO in the slag is combined with silica, rendering it inactive toward the metal. This neutral, "almost" reducing condition of the slag may account for the slight amounts of chromium which have been reduced into the metal on chromium heats. An increase of 0.15 to 0.20 per cent between two tests sent to the laboratory an hour apart has not been uncommon.

Pouring Forging Ingots

A detailed discussion of pouring practice would constitute a paper in itself. It is my intention to give merely a general view of some of the problems involved in a plant where a great variety of ingots are produced. The sizes of the ingot molds used at Midvale range from a 9-inch square to a 108-inch octagon. The lightest ingot poured is 600 pounds and the heaviest is 500,000 pounds. The cross sectional shapes of the molds vary from squares to rounds. In between this range are octagons, dodecagons and various types of fluted ingots, the relation of the corners and sides to the number of sides depending on the purpose for which the ingot is intended.

There are four methods of pouring practiced. They are as follows:

1. Bottom pouring through a runner
2. Top pouring directly into the mold
3. Top pouring through a head box
4. Combination of top and bottom pouring.

Bottom pouring offers a number of advantages for certain types of work. The stream of metal enters the runner which is only a few inches below the ladle nozzle and is introduced into the bottom of the mold without splashing. Thus the stream is protected from the oxidizing effect of the air and there is no splash in the mold which would also cause oxides to be formed. It is the most ideal method for introducing the metal into the mold from the viewpoint of producing clean steel with a good surface. Depending on size, ingots may be poured in this manner in groups from the same runner. In the case of light ingots, as many as fourteen may be poured at the same time.

The chief advantages of bottom pouring, namely, good surface and less chance for the formation of oxides, due to splashing, make it indispensable for certain types of work. There is one disadvantage to bottom pouring, but it can be overcome to a great extent. In pouring an ingot from the bottom entirely, the metal at the top will be cooler than the metal at the bottom. This condition is not desirable, as it is conducive to the formation of pipes and secondary shrinkage cavities. However, by pouring only the body of the ingot from the bottom and then filling up the sinkhead from the top, this condition can be eliminated. We very rarely find an ingot piped when poured by this method. Pit work in connection with bottom pouring must be done with great care. All dirt must be removed from the runners, or the added expense of bottom pouring will be in vain. It is by far the most expensive method of pouring. The expense is in runner bricks and labor.

Pouring from the top directly, the cheapest method, is satisfactory in some cases. Excessive splashing, especially at the bottom of the mold, may occur, due to the large head of the stream. A defective nozzle or plug, causing a poor stream from the ladle, puts one in a helpless position when pouring by this method.

Top pouring through a head box gives satisfactory results

for many types of work. Generally a good solid stream may be obtained from the nozzle of the head box and, because of its reduced head, will not cause excessive splashing in the mold. This method offers much better control of pouring speed than the direct method.

It is useless to argue about the relative merits of top and bottom pouring without considering the purpose for which the

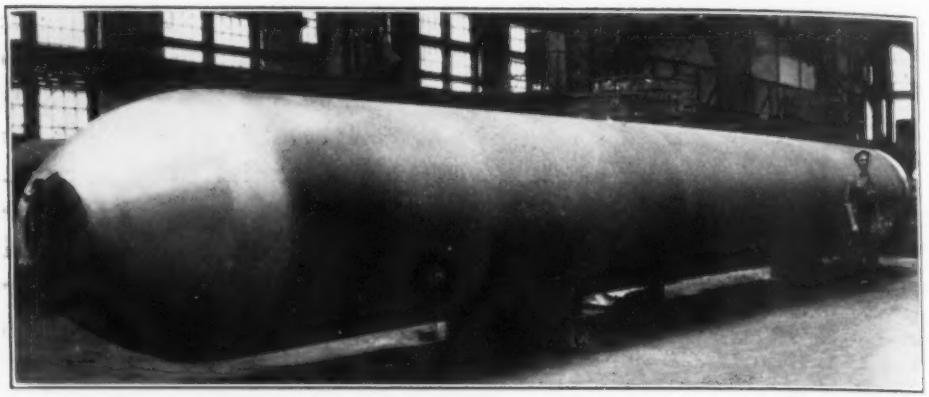


Fig. 2—Photograph Showing a Drum Made from an 108-Inch Octagon Ingot Similar to that Shown in Fig. 1. This Drum is Used in Steam Boiler Construction.

ingot is intended. In some cases bottom pouring might be a needless expense. In other cases, top pouring involves great risks.

In regard to tapping and teeming temperatures, no specific temperatures will be given. These temperatures vary considerably with the various grades of steel made. However, in general it has been found to be the best practice to tap fairly hot and hold in the ladle as long as is practical. During the time it is held in the ladle the metal has opportunity to clear itself of oxides formed during tapping. Slag particles driven into the metal may also have time to rise.

The pouring temperature should be sufficiently high to allow oxides formed during teeming to become eliminated. It has been found that the practice of pouring "cold as possible" results in excessively dirty steel. On the other hand, pouring extremely hot will result in undue segregation. Poor ingot surface is also associated with a too high pouring temperature. Naturally a happy medium must be struck. The design of the molds used is also to be considered in this problem. Some have generalized on the subject of hot pouring and segregation without so much as men-

tioning the size of the ingot or the design of the mold. To predict the possible effect of a certain teeming temperature without considering the design of the mold is faulty reasoning.

It is reasonable to believe that the speed with which an ingot is poured will have some influence on its character. Experience has set a standard for each grade of steel. Especially in the case of alloy steels it has been found that pouring fast causes trouble. In most cases where, due to some mishap in the pit, a heat has been teemed unusually fast, trouble will be experienced in the forge with these ingots. "Pulls" and "corner cracks" are often attributed to fast pouring. Selection of the proper size nozzle to pour a certain grade of steel into a certain sized mold requires judgment that can only be gained by long experience.

The production of medium sized ingots weighing from 50,000 to 100,000 pounds does not entail difficulties not experienced with light ingots. However, in the case of heavy ingots in the neighborhood of 400,000 pounds many new problems are met with. It may be of interest to describe the practice employed in the casting of a plain carbon steel ingot weighing 420,000 pounds.

The cast iron 108-inch mold is set on a suitable bottom. It is fitted with a runner through the bottom and has a head box set on the sinkhead flask. Three furnaces are necessary to furnish the metal for this ingot. The furnaces are tapped at predetermined times. The first heat is poured partly through the bottom. The depth of the "pool" poured in this manner varies with the composition of the steel. After the desired pool is poured from the bottom, the ladle is quickly moved over the head box. The balance of the ingot body is poured in this manner. The sinkhead is generally poured rather slowly to increase the "feeding effect" desired.

Co-ordination is the prime factor in successfully producing such ingots. After actually timing all operations in casting six ingots of the same weight and poured with the same size nozzles, it was found that the total time required for each did not vary more than five minutes. The average time from opening the first nozzle to finishing the sinkhead was one hour and ten minutes. The total intermission, namely, when the first ladle was moved from the runner to the headbox, was only 10 seconds. After once starting to pour through the headbox no intermissions occur. Metal continues to flow from the headbox while the ladles are being

moved from it and to it. It was noted in the time study that the tapping of each furnace was within one minute of the designated time. It is necessary to take every possible precaution to prevent delays of any kind.

Having three furnaces come to a desired point, ready to tap at practically the same time, taxes the melter's skill to the utmost. The mechanical department also has a serious responsibility. A crane breakdown causing a delay would be fatal. Every possible precaution must be taken to avoid such an occurrence. The pit work must be as near perfect as possible. It might be mentioned that practically a week's time is necessary to prepare the pit for the casting of such an ingot.

In closing the writer wishes to express his appreciation to Radclyffe Furness for his kind assistance and helpful criticism in preparing this paper.

STAINLESS IRON AND ITS APPLICATION TO THE MANUFACTURE AND TRANSPORTATION OF NITRIC ACID

By Dr. Walter M. Mitchell

Abstract

The unique and spectacular development of the stainless irons—because of their importance to chemical industries as materials for the handling of nitric acid—is described; together with the importance of this acid to various industries as a source of available fixed nitrogen. A short account follows of the recently developed ammonia oxidation process for the manufacture of nitric acid.

The resistance of various materials to nitric acid is discussed, and the superiority of the high chromium alloys for this purpose described. Requirements as given for suitable materials for the construction of equipment for the manufacture and transportation of nitric acid.

Existing specifications for stainless iron for this purpose are critically examined, the discussion considering in detail specifications for plates, rivets, tubing, castings, tank cars, shipping drums, etc.

THE old saying that "necessity is the mother of invention," was never better illustrated than by the development of the stainless irons which has taken place in the last few years. Previous to 1925, these high chromium alloys were produced in lots of a few tons only. But with the realization by chemical industries of their tremendous potential importance as a material for the construction of equipment for the manufacture and handling of nitric acid, production has increased to hundreds of tons and the alloys have assumed prominence exceeding the fondest expectations of the metallurgical optimist. When we recall that only a few years ago rivet heads were flying off with great spontaneity, valves and fittings were being machined laboriously by hand from bar stock of uncertain quality, one-piece dished heads of 10 feet diameter were considered highly impractical, and cast-

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ings were virtually unobtainable, the extraordinary development that has taken place may be appreciated. And for this development we must thank the chemical industry for providing the necessary stimulus. But for its incessant and insatiable demands for all sorts of plant equipment, we must regretfully admit that this phenomenal development would probably never have taken place.

The writer considers himself fortunate in having been privileged to witness this development from its beginning, and to have had some small connection with it. It is believed worthwhile, therefore, in view of the importance of these alloys, and the fact that still larger tonnages will be required in the near future, to consider their characteristics and to discuss specifications which describe materials suitable for nitric acid manufacturing equipment. Before taking up the metallurgical side of the subject, it will be of interest to consider the position of the chemical industry and some of the causes which have made this development of stainless alloys necessary.

Requirements of the Chemical Industry

In chemical industries, the selection of materials for the construction of apparatus for the manufacture of products which are by nature corrosive is one of the most important problems to be solved. No process can be considered complete or commercial until materials have been secured for the equipment necessary for its large scale operation. In the past, the importance of this was overlooked, perhaps because many of the processes were simple and a fairly satisfactory material was easily found; or, corrosion was accepted as inevitable, and the matter rested at that. But with the advent of the newer synthetic processes, the problem has become much more important. When we realize that for the synthesis of ammonia according to the Claude process containers must be secured which will withstand pressures of 15,000 pounds per square inch at 1000 degrees Fahr., and at the same time be immune to the action of hot hydrogen, the difficulties encountered may be appreciated.

The production of nitric acid by the oxidation of ammonia is a somewhat simpler type of process, and it is fortunate that metals, the high chromium-iron alloys, which satisfactorily resist this acid, are already available.

Until the introduction of ammonia oxidation, nitric acid was produced from sodium nitrate (Chile saltpeter) obtained from the nitrate beds of Chile, by distillation after mixture with strong sulphuric acid, according to the reaction.

$$NaNO_3 + H_2SO_4 = NaHSO_4 + HNO_3$$

The acid sodium sulphate which remained as a byproduct being the familiar "niter cake."

Owing to the eventual exhaustion of the Chilean nitrate beds and the high cost of nitrogen compounds so obtained, the securing of other sources of available nitrogen becomes necessary if human life on this planet is to continue. The largest supply of nitrogen is the earth's atmosphere, and when we realize that over each square mile of the earth's surface there is estimated to be about 20,000,000 tons of available nitrogen, the inexhaustible nature of this supply will be readily apparent. But as present in the atmosphere, nitrogen is a colorless, inert gas combining with few other elements, and with these only at very high temperatures, and is hence not in a form suitable for use in any industry.

The importance of nitrogen to our domestic economy can hardly be over estimated. It is an essential constituent of the most important compounds in nature and industry. Its two most important products, ammonia and nitric acid, are used as sources for the manufacture of fertilizers, the demands for which are growing day by day. Nitrogen enters into the composition of virtually all explosives, innumerable dyestuffs, artificial silk, and almost all organic drugs used in the medical profession. Nitrocellulose products such as lacquers for the automotive industry, motion picture and other photographic film, celluloid and similar plastics for toilet articles and novelties also require nitrogen for their production. But of more interest to the metallurgist is the recently perfected nitriding process of hardening steel with nitrogen by heating in an atmosphere of ammonia, which, if the process proves as successful as experiments indicate, will certainly revolutionize certain branches of practical metallurgy.

To discover a process of "fixing" the nitrogen of the atmosphere into some form in which it would be available for the manufacture of chemical and other products has been the aim of chemists for many years. Numberless processes have been developed,

but only three have stood the test of time. These are, first: The "direct arc," in which air is heated to a high temperature by passing through an electric arc, under which conditions a small proportion of nitrogen combines with oxygen to form nitric oxide (NO). Fortunately for us, this reaction takes place only at the highest temperatures, otherwise the smallest flame would ignite the atmosphere and a deluge of nitric acid would follow. From the oxide (NO) the peroxide (NO_2) is formed by a further reaction which takes place spontaneously at lower temperatures, and this may be converted into nitric acid by combination with water.

The second important process is the cyanamide process, which will be used at Muscle Shoals, if operations are ever begun at that plant. It depends upon the combination of atmospheric nitrogen with calcium carbide at a high temperature to form calcium cyanamide ($CaCN_2$). This may be used "as is" for fertilizer, or by combination with water converted into ammonia. The latter, in turn, may be converted into ammonium sulphate, which is a more satisfactory fertilizer, or oxidized to produce nitric acid.

The third process is the direct synthesis. This consists in the combination of gaseous nitrogen and hydrogen in the presence of a catalyst at high temperatures and pressures to form ammonia (NH_3). It is the most recent of the fixation processes and is now being carried on successfully on a large scale at several plants. There are three main variations of this process as controlled by different patents, the differences being chiefly in the pressures and temperatures.

The nitrogen used in the latter two processes is extracted from the atmosphere by any of several methods. In one process, the oxygen is burned out by combustion of hydrogen, the nitrogen remaining. In another, it is extracted by distillation of liquid air. As nitrogen boils at a lower temperature (—195.5 degrees Cent.) than oxygen (—183 degrees Cent.) it is possible to boil off the nitrogen, leaving the liquid oxygen behind. The hydrogen used in the direct synthesis process, and in extracting nitrogen from the atmosphere, is usually obtained from blue water gas.

It will be of interest at this point to consider briefly the extent to which the nitrogen industry has grown during the few years since its inception.

The world's total production of inorganic nitrogen for the

year ending June, 1927, totalled 1,446,000 tons, of which 20 per cent was produced from Chile saltpeter, 24 per cent from by-product ammonia, and the balance, 56 per cent, from atmospheric nitrogen fixation processes. Of the 807,000 tons represented by the last figure, less than 5 per cent was fixed by the arc process, less than 22 per cent according to the cyanamide process, while the balance, 73 per cent, or 593,000 tons, was fixed according to the direct synthetic ammonia process.

Comparing these figures with those of the year previous, it is clearly seen that the trend of increased production is with the newer synthetic process, and that this is leading the older processes by a considerable margin. Germany, of all countries of the world, is by far the largest producer. Of the 593,000 tons of fixed atmospheric nitrogen produced in 1927, Germany contributed 440,000 tons (76 per cent); and Germany's dominance in the early stages of the War, and her ability to maintain the efficiency of her fighting forces by ample supplies of explosives, may be traced directly to the adequacy of her nitrogen fixation plants.

In the arc process, nitric acid may be produced directly; but in the cyanamide and the synthesis processes, ammonia is produced and this, in turn, must be converted into nitric acid. The oxidation process by which this is done has been described by Taylor[1] and is briefly as follows:

Gaseous ammonia mixed with air is passed through red hot platinum gauze, which acts as a catalyst, in a converter, the nitrogen combining with the oxygen to form nitric oxide.

$$4NH_3 + 5O_2 = 6H_2O + 4NO$$

After passing the platinum gauze, the gas mixture is cooled and the nitric oxide further oxidized to nitrogen peroxide, according to the reaction,

$$2NO + O_2 = 2NO_2$$

This is then passed into absorption towers in which a spray of water is continually falling and is converted into nitric acid by reaction between the water and the gas,

$$3NO_2 + H_2O \rightleftarrows NO + 2HNO_3$$

[1] *Industrial and Engineering Chemistry*, Vol. 19, p. 1250, 1927; see also Spangler, *Chemical and Metallurgical Engineering*, Vol. 35, p. 342, 1928.

The nitric oxide formed is again converted into the peroxide which, in turn, becomes nitric acid.

While the above is the general outline of the chemistry of the process, there are various modifications in use, the details of which would be out of place here. There are, however, two important modifications of the process that should be noted here; namely, in the pressures at which the oxidation is conducted. In the first, this is at atmospheric, or nominal, pressure, yielding a 50 per cent acid. In the second, operations are carried on under high pressure—100 pounds per square inch—producing a somewhat higher concentration acid. The advantages of the latter system are in the greatly reduced size of the plant and equipment, and the higher concentration of the acid which is at once obtained. Obviously, the operation of either process on a commercial scale depends upon the availability of suitable materials for the equipment, and it is with this phase of the subject that the balance of this paper will be concerned.

It is well known that nitric acid attacks most metals even at ordinary temperatures, exceptions being the noble metals such as gold, platinum, iridium, etc., which are too costly for use, and the more common metals aluminum and chromium. Previous to the introduction of chromium alloys, the only commercial materials in which nitric acid could be handled were stoneware and vitreous materials, the high silicon irons (13 to 15 per cent silicon), and aluminum. Iron, which is fairly resistant to highly concentrated acid, is rapidly attacked by dilute acid and hence is not usable.

Stoneware and vitreous materials are objectionable because of their fragility. They are limited in shapes and sizes in which they may be produced, and the necessity of cemented joints makes their use still more unsatisfactory. The iron-silicon alloys, while excellent as regards corrosion, suffer the same disadvantage. Aluminum is generally satisfactory for cold, dilute or concentrated acid, but is not serviceable when the concentration of the acid is around 20 to 30 per cent; while with increase in temperature, the rate of attack for all concentrations is increased. But the recognition that the iron-chromium alloys of the stainless analysis were highly resistant to nitric acid has brought about a complete change in the situation. These alloys, made with low carbon, may be produced in virtually all necessary forms, have

ample strength and toughness, can be fabricated without undue difficulty, and are not prohibitive in cost compared with vitreous materials.

While the stainless alloys are not resistant to crude nitric acid produced by the older process from Chile saltpeter because of the high content of chlorides, bromides and iodides, all of which attack chromium, the purified acid is satisfactorily resisted, as is acid produced by the oxidation of ammonia, which is free from such impurities. Hence, the interest of the chemical industry in these alloys.

Specifications for Materials

The purpose of a specification is to describe the properties required of a material, such as strength, ductility, corrosion resistance, etc., in order to be suitable for a given purpose; and to be a basis for the purchase of such materials by a consumer. At the time of preparation of the specifications used by the duPont Co., and these are still in use with very little modification, very little was known about the properties of stainless irons. Perhaps this was fortunate, for it doubtless prevented the inclusion of a number of acrobatic stunts which the metal would have to perform to demonstrate its suitability. As a matter of fact, there is much still to be learned about these metals, and more experiments must be completed before we become fully acquainted with their characteristics. But with increased knowledge, the attempt should be made to keep specifications as simple as possible for the mutual benefit of both manufacturer and purchaser.

The largest tonnage of stainless iron will be consumed in the construction of the acid manufacturing plants themselves; but in addition to such installations, equipment for transportation of acid will be required. This includes tank cars, and shipping drums of various sizes. Tank cars are already being constructed, and drums of various compositions have been experimented with for some years, but of this more later.

While the stainless irons are distinctly stronger and tougher than low carbon steels used for structural purposes, and hence have ample strength for any ordinary equipment, they have individual peculiarities which necessitates special provisions in any set of specifications to prevent the entrance of material which

would prove unsatisfactory in service. Specifications should therefore provide:

1. A metal which will have ample corrosion resistance for the purpose. In this case, corrosion resistance is purely a matter of the composition and quality of the metal. Therefore, proper composition must be specified, with whatever tests are necessary to demonstrate its freedom from slag inclusions, excessive grain size, etc.
2. A metal which will have the necessary strength and ductility for purposes of fabrication. Ductility is highly important. Unfortunately, the stainless alloys of the high chromium range have inherent propensities for becoming brittle if improperly handled in mill operations. Hence, ample bend and other ductility tests must be included to prevent brittle material being furnished. Greater weight should be given to such tests than to tensile tests made merely for strength.

Specifications covering stainless irons have been prepared by E. I. duPont de Nemours and Co., The Atmospheric Nitrogen Corp., Chemical Construction Co. and others. For obvious reasons, no attempt will be made to identify the various details of the specifications discussed in what follows with any of these companies.

Chemical Composition

The first specifications made a distinction between various chemical compositions in accordance with trade names and the different patents under which the steel producers operated. This distinction has now disappeared and specifications call for actual composition only.

The chromium content is the all-important factor which determines resistance to nitric acid. An alloy with 14 per cent chromium will resist concentrated acid, but not the very dilute acid. A chromium content of 16 per cent, however, will resist any concentration of cold acid, and is only very slightly attacked by hot acid. In consequence, a minimum of 16 per cent chromium has been generally specified by all companies, with the exeption of one, who consider 17 per cent the proper minimum. The maximum is limited at 19 to 20 per cent. The higher cost

of the higher chromium alloys, and their more difficult workability set a natural upper limit.

Carbon is to be maintained low, always under 0.12 per cent, except for castings, which will be discussed later. Low carbon is desirable, to avoid air hardening tendency and brittleness in case the metal should inadvertently be heated to a too high temperature. The lower the carbon, and it may easily be held to 0.10 per cent maximum, the greater the ductility of the metal.

The silicon content has lead to considerable discussion because of the higher percentage in alloys produced under Armstrong patents. Those who have listened to the emissaries of the holders of the Haynes and Brearley patents have restricted silicon to 0.50 per cent maximum. According to Monypenny[2] silicon is desirable because it appears to increase resistance to mineral acids to a slight extent at least, and to reduce air hardening tendencies. There is no question but that a small addition of silicon is a distinct advantage, particularly to the steel maker, both in the melting process, and in mill and fabricating operations, where it facilitates hot working. Excessive silicon, however, is quite undesirable since it encourages grain growth and lowers resistance to shock. It is difficult to set an exact limit, but a safe limit appears to be about 1.0 per cent maximum for bar stock for rivets, bolts, nuts, etc., and 1.10 per cent for plates, tubing, etc.

To the advocates of low silicon who claim that an addition of this element makes the metal undesirable for riveted structures, especially the rivets themselves, it can be stated that their fears are unwarranted. Large quantities of rivets of the high silicon composition have actually been used and have given entire satisfaction. To condemn a metal simply because it becomes unreliable when improperly handled shows poor metallurgy.

The percentage of manganese is important from the standpoint of corrosion resistance, and this element should be held low, 0.35 to 0.40 per cent being a satisfactory limit, and in no case should 0.50 per cent be exceeded. Experiments[3] indicate that manganese distinctly lowers the corrosion resistance of chromium

[2]Stainless Iron and Steel, p. 164.

[3]*Chemical and Metallurgical Engineering*, Vol. 34, p. 417, 1927.

alloys and that 1.00 per cent will offset the effect of some 9.00 per cent chromium.

Phosphorus and sulphur may easily be maintained low, and are usually specified at 0.025 per cent to 0.030 per cent maximum. From the scanty information available they appear to affect corrosion resistance adversely.

The nickel content is important. The first effect of added nickel on physical properties of stainless alloys is lowering of the critical range and increased tendency toward air hardening. With nickel above about 2 per cent, stainless steels gradually become martensitic and are commercially unimportant. With nickel over about 7 per cent and chromium 16 per cent the alloy becomes austenitic with properties characteristic of alloys of this type. It was originally supposed that nickel reduced resistance to nitric acid, even if present in small quantities. Specifications accordingly restricted nickel to 0.40 per cent and in some cases to as low as 0.25 per cent. This latter figure was not always easy to maintain because of the contamination of practically all scrap with at least a small proportion of nickel.

Fears regarding corrosion resistance seem to be ill founded because nickel in reasonable proportions does not appear injurious, although evidence for this is not altogether complete. Certain strengths of acid, particularly "C. P." acid may have a slight tendency to attack, but the commercial or strong acids seem to be free from effect.

Interest in austenitic chromium-nickel alloys lies in their better welding qualities compared to straight chromium iron. For this reason chromium-nickel alloys of the "18 and 8" analysis are preferred for acid shipping drums which must be constructed by welding. Also because of the greater ductility of alloys of this type and their somewhat "fool proof" characteristics, particularly in respect to overheating, it seems very probable that future nitric acid installations may be made from them. At present the greatest drawback to their use is higher cost.

Copper is not ordinarily a constituent of stainless alloys. Its presence, because of its readily oxidizable nature, would seem objectionable on theoretical grounds. Specifications usually restrict copper to 0.2 per cent or less where it is considered merely as an impurity.

Plates

Plates are used for construction of absorption towers, tanks, tank cars, large size piping, and various other parts of equipment. Two main processes for the oxidation of ammonia have been described. In one, operations are carried on under high pressure (100 pounds per square inch). In the other, under nominal or low pressure. In the latter process the absorption towers are constructed as large as can conveniently be fabricated. On account of the careful procedure required in riveting, field construction of towers has not been attempted. This necessitates construction in the shop, and shipment assembled to the plant site for erection, which restricts diameter to about 10 feet and height to 50 to 60 feet.

For the 10-foot towers ¼-inch plate is used, except for the lower courses which are made from ⅜-inch plate. As pressure is nominal no particular strength is required beyond that the structure will not be in danger of collapsing. In the high pressure system, and this is its great advantage, one smaller tower replaces a number of large ones. This tower is usually made of ⅜-inch plate. For such plates it is obviously essential that all tensile tests be passed satisfactorily.

Plate specifications require the following minimum physical properties,

Tensile Strength	70,000 pounds per square inch
Yield Point	45,000 pounds per square inch
Elongation in 2 Inches	25 per cent
Reduction of Area	50 per cent

These physical properties are within the range of plate material and, except for reduction of area, are satisfactory. Reduction of area on plate or sheet specimens is difficult of measurement and subject to considerable uncertainty. It should hence be omitted.

All plates should be annealed to remove strains, to soften, and to diminish the possibility of cracking when shearing edges and punching rivet holes. Very careful procedure with proper support for the plates is necessary during the operation to prevent warping and buckling.

Removal of scale by pickling or sandblasting is required, both because of improved corrosion resistance, and for prevention of possible leakage resulting from the attack on the scale where

scaled plates are riveted together. Specifications call for various strengths and combinations of sulphuric and hydrochloric acid. A suitable bath is composed of 10 per cent sulphuric and 5 per cent hydrochloric used at a temperature of about 140 degrees Fahr. It would seem best, however, to leave this to the steel manufacturer, the specification demanding that the plates shall be free from scale.

Thorough washing is advisable after pickling. As the pickling bath will rarely work uniformly, and prolonged pickling necessary to remove all traces of scale may roughen up the plate, spot grinding may be resorted to provided this does not reduce the thickness below gage.

A word of advice regarding annealing and pickling at this point may be worth while. To do a satisfactory pickling job the plate should be pickled both before and after annealing. Annealing without previous pickling bakes on the scale from rolling to such an extent that it is virtually impossible to remove it in any pickling bath. Annealing should be done in an oxidizing rather than reducing atmosphere as the scale produced under such conditions is far easier to remove.

Sandblasting produces a much smoother surface than pickling, and as it will cut away the toughest scale would seem a far better method. After sandblasting, however, all plates should be given a slight pickle in dilute hydrochloric acid for the purpose of bringing to light defects such as slivers, scabs, splits, etc., also any unreasonably coarse grained structure,—a sort of macro-etch.

Following pickling or sandblasting, a nitric acid bath is necessary, its purpose being removal of any particles of scale that might remain or have been driven into the surface by the sandblast; also to pacify the metal and increase corrosion resistance. Various strength and temperatures are specified for this bath, from 10 to 33⅓ per cent acid and from cold to 110 degrees Fahr., from a few minutes to an hour or more. A proper specification for this bath is not less than 10 per cent concentration of acid with immersion for not less than ½ hour at room temperature. The stronger the acid and the longer the time the better.

The bend test was introduced to prevent supplying of plates too brittle for fabrication. The American Society for Testing

Materials Specifications for boiler and firebox steel (serial A30-24) demand that the specimen shall stand bending cold through 180 degrees without cracking around a bar, or mandrel, the diameter of which is equal to the thickness of the specimen for plates 1 inch thick or less, and twice the thickness of the specimen for plates over 1 inch thick; the specimen to be cut from the side of the plate in the direction of rolling, i.e., longitudinally. Such a specification is entirely satisfactory for properly annealed stainless iron of any reasonable analysis, but on account of the more fibrous nature of stainless iron compared with low carbon steel a transverse bend test should be also included.

The transverse test specimen, which is to be taken from the end of the plate across the direction of rolling, should stand bending cold around a bar similar to the longitudinal test, 120 degrees for plates 1-inch thick, or less, and 90 degrees for plates over 1-inch thick.

The existing specifications of the various chemical companies mentioned are in some cases more rigorous, requiring a flat 180 degree bend without an intervening bar, and in others not as rigorous, requiring a bend of only 120 degrees; around a bar of the same thickness as the plate, even for the longitudinal test. As a matter of fact any specimen of stainless iron plate ¾-inch thick with carbon under 0.12 per cent if properly rolled and annealed will bend flat on itself without cracking in the direction of rolling. Tests taken across the direction of rolling will show about one-half to two-third the bending quality of the longitudinal specimens.

A homogeneity test similar to that of the American Society for Testing Materials boiler and firebox steel specificaton is desirable and should be included. Laminated structure sometimes occurs in plates, particularly in the higher chromium analysis, and it is obviously desirable that such defective plates be excluded. Two chemical companies' specifications include a quality test which provides for microscopic examination or a deep etch test, "the basis for rejetion to be agreed upon by the manufacturer and purchaser"—which does not mean anything in particular.

One-piece dished and flanged heads are used for the ends of the absorption towers. No particular difficuty has been experi-

enced in producing these up to 10 feet in diameter. But as the plate in the finished heads cannot be tested without destroying the head comparative hardness tests are provided, the basis for acceptance being agreement of Brinell or scleroscope readings within 10 per cent of those obtained on plate material known to be satisfactory. Heads should be annealed after the final spinning operation and all scale removed as with plates.

Rivets

Rivets are probably the most important of the stainless products used in construction, for the success of the finally fabricated structure depends upon their holding together and staying in place. Riveting with stainless rivets nearly wrecked the whole development at the outset because of the facility with which chromium alloys air harden if improperly handled. Workmen accustomed to heating steel rivets to 1900 or 2000 degrees Fahr. did the same with stainless rivets only to see the heads snap off when cold or at the slightest blow of the hammer. Fortunately means have been found to prevent such casualties, and it is now possible to drive stainless rivets which are apparently as strong as steel rivets of similar dimensions.

At the time of preparation of the first specifications there was much concern lest there be recurrence of the failures above reported on some inconvenient occasion after operation of the plant had begun. This, together with considerable uncertainty as to just what could be expected of this metal lead to the inclusion of rather elaborate tests for both the bar stock from which rivets were to be made, and for the finished rivets. Minimum strength requirements for rivet stock were as follows:

Tensile Strength	60,000 pounds per square inch
Yield Point	40,000 pounds per square inch
Elongation in 2 Inches	25 per cent
Reduction in Area	50 per cent

Two companies have since raised the tensile strength and yield point to 70,000 and 45,000 pounds per square inch respectively. There can be no objection to this, and these figures may well be adopted as standard, since they are within the possibilities of the material.

To detect possible brittleness in rivet stock a cold bend and a hot quench bend test were specified. The cold bend requires that

full diameter sample bar shall stand bending cold 180 degrees flat on itself without cracking on the outside of the bent portion. The hot quench bend test provides that full diameter sample bar shall stand bending cold 120 degrees around a mandrel equal to its diameter after being quenched in oil from 1400 degrees Fahr. The object of the latter test is to imitate in a way, actual riveting conditions by heating the specimen to the riveting temperature and cooling rapidly as the rivet is cooled when driven into the cold plate. If the metal will stand this rather severe bend after an oil quench it is presumably sufficiently tough for manufacture of rivets.

Thorough inspection of the surface of rivet stock is highly important. The largest manufacturer of stainless rivets expresses his views on this point as follows:

> "A ground surface seems to give a better product than a drawn surface. We conclude that this is due to the fact that a ground bar is free from the scratches that are so difficult to avoid in drawing, and also any guide scratches that may have been produced in rolling.
>
> "The upsetting specifications of many users are so severe that any scratch on the bar is liable to open up and cause rejection.
>
> "Stainless iron possesses a 'pick up' property which may be described as a tendency to adhere to most ferrous metals that are brought in close contact with it. This property necessitates the smoothest possible finish for various classes of work that are to be put through dies, such as bolt and rivet dies, drawing dies, etc.
>
> "It also appears advisable that all bars be subjected to a white pickle at the mill, and rigidly inspected before shipment to the fabricator. This will ensure the removal of most defective bars before any time and money is spent on them, and will reduce the loss to both the fabricator and the mill which is usually required to replace material that cracks in upsetting."

One specification requires a hot upset test for rivet stock which provides that a full sized specimen of bar shall stand upsetting from a length of 1½ diameter to a length of ½ diameter when heated to 1400 degrees Fahr. without cracking or splitting.

This is a very desirable test and in a way duplicates riveting conditions.

Rivets may be manufactured cold or at a temperature of 1400 degrees Fahr., which is below the critical range of the metal. The advantages of cold manufacture were ascertained from the results of a large number of tests made with experimentally riveted plates. Two pieces of ¼-inch plate of convenient size were riveted together with rivets of various types which had been heated to a variety of temperatures. A wedge was then driven between the plates until something gave way, or the plates opened up to an angle of 20 to 30 degrees. Any rivet which would stand this test was considered good. The tests developed a number of interesting facts; namely, that if any rivet head failed, it was almost invariably the original upset head and not the driven head; also that a greater number of hot upset heads failed than cold upset. Apparently the double heating of the hot upset head for the original forming and subsequent driving is detrimental to the toughness of the metal. To overcome this, conical, instead of button, heads were specified, the idea being that the work done on the metal while reducing from cone to button shape would improve its condition; and results of further tests seem to confirm this. With cold upset heads and hot driving there is only one heating for both heads, and this heating presumably removes cold working strains remaining from the original upsetting operation. If the cold upset head is cold driven, the condition of the metal in both heads should be similar. Therefore, specifications should require cone headed rivets for hot driving, and cold upset button heads for cold driving. As stainless iron is rather stiffer than plain rivet steel it has been found impractical to cold upset or cold drive rivets larger than ¾ inch.

Tests of finished rivets are equally important to tests of rivet stock, and these should include bend and flattening tests. Bend tests are made cold and provide that the finished rivet shall stand bending cold at 180 degrees flat on itself without cracking. This is a desirable, but impractical, test which was copied after the American Society for Testing Materials specification for boiler rivet steel (A31-24). It is impractical, because the rivet shank is usually too short to be gripped in a vise and still allow suffi-

cient length for a 180-degree bend. This specification should be altered by substituting a 90-degree bend for the 180-degree. One user specifies that the bend shall be 90 degrees around a mandrel equal in diameter to the rivet shank, but this is just as impossible. The best requirement is a 90-degree bend without mandrel, or at least as great a bend as the length of the shank will allow.

Each stainless iron rivet should be marked with an identification symbol to distinguish it from plain steel rivets. It is highly important that no steel rivets be used. The absorption towers are packed with terra-cotta or tile rings over which the dilute acid trickles while exposed to the action of the NO_2 gases. If a steel rivet were accidentally included it would dissolve out in a few days necessitating the removal of the rings so as to make proper repairs. Obviously a laborious and expensive proceeding.

To avoid just this possibility one set of specifications originally included the simple expedient of immersing all rivets in a nitric acid bath for ten hours. This is a simple and sufficient test, for after ten hours any steel rivet would probably be nonexistant. But it involves considerable delay, and a shorter test, providing immersion in 10 per cent acid at 180 degrees Fahr. for one hour, has been substituted; any rivet showing signs of attack to be rejected. A more convenient test is the well known spark test, the difference in the sparks obtained from stainless iron and plain steel being so distinct that detection of the wrong metal is unquestionable. This also has the advantage that with a small portable grinder rivets already driven may be tested with certainty.

As a precaution against failure rivets should have a $\frac{1}{16}$-inch radius fillet under the head. One purchaser goes still further and requires that the rivet holes be countersunk on both sides of the plate.

Where rivets are driven hot they should be heated in an indirect fired furnace equipped with a pyrometer to a temperature not exceeding 1400 degrees Fahr. Actually, this temperature may be exceeded by possibly 150 degrees Fahr. without the strength of the rivets being seriously impaired, but 1400 degrees Fahr. is a safe limit. Rivets should not be held at driving temperature for longer than 30 minutes. Such extreme precautions may seem exaggerated in view of the fact that rivets may be driven which will

withstand many blows with a heavy sledge without failure; but the very serious expense and delay incurred if any rivet should require replacing makes every precaution desirable.

Tubing and Piping

The production of seamless drawn tubing presented many difficulties at the start and much "grief" was experienced before production in commercial quantities was an accomplished fact. Difficulties were encountered in both the piercing and the drawing operations, but these have now been successfully overcome, and drawn tubing in a range of sizes up to 5 or 6 inches outside diameter, in practically all stainless iron analyses, can readily be obtained. Still larger sized seamless tubing is being produced by forging a pierced billet on a mandrel to the proper length and diameter, also by turning up the outside of a large forged cylindrical billet and removing the core by a trephining operation. Truly an expensive procedure in either case.

In plant construction tubing is used for pipe lines, heat exchangers, condensers, etc. It must therefore possess certain definite qualities; namely, sufficient ductility to be bent and flanged without splitting, freedom from seams and porosity so as to be gas tight, accurate uniformity in size to permit the attachment of fittings, etc., without extra machine shop work.

As tubing is produced in virtually all low carbon analyses the question of special compositions may be disregarded and the same analysis demanded as for plates and rivets. For heat exchangers, which are subjected to higher temperatures a more heat resisting material may be required. The austenitic chromium-nickel alloys of the "18 and 8" composition may be used for this purpose.

At this point an interesting peculiarity of the stainless alloys should be mentioned, and this is of especial import in connection with the fabrication of tubing. The straight chromium irons of the 16 to 19 per cent range show decidedly increased ductility and working qualities when heated to a few hundred degrees than when stone cold. This increase in ductility seems out of all proportion to the temperature change, but bending and flanging tests which are practically impossible if attempted stone cold may easily be done when the temperature of the metal is some 200 to 300 degrees Fahr. This is not true, however, for the "18 and 8" analy-

sis which has sufficient ductility in the cold and does not require this slight heating for bending or forming.

Several of the chemical companies include a tensile test for tubing. Tensile test specimens cut from tubing can hardly be considered as giving results comparable to those from bars or plates. Further it is seldom that the longitudinal strength of tubing is important. The transverse strength determines its resistance to internal pressure and renders it a useful, or useless, material. In consequence, hydrostatic pressure tests have been incorporated in the specifications of two of the chemical companies. These provide that each length of tubing shall be subjected to the cold internal hydrostatic pressure determined by the formula,

$$P = 40{,}000 \frac{t}{D}$$

Where P equals the pressure in pounds per square inches, t is the tube wall thickness in inches, and D the outside diameter in inches.

Flanging and flattening tests are required in all specifications, and these follow the general arrangement of the American Society for Testing Materials boiler tube specifications (A83-27), with the exception that flanging tests for stainless iron provide that the tube shall have a flange bent over cold (under 250 degrees Fahr.) at right angles to the body of the tube without showing cracks or flaws. Such flange, measured from the outside of the tube, shall in no case be less than ¼ inch or more than ½ inch in width. This is an important test since Van Stone joints are ordinarily used in chemical plant construction. They are more easily taken down than threaded joints, which, with stainless alloys, have a most unpleasant tendency to seize and stick.

The flattening test provides that a short length of tubing shall withstand flattening cold (under 250 degrees Fahr.) between parallel plates without cracking or showing any flaw until the distance between the plates is some multiple of the tube wall thickness. One company demands that this distance shall be twice the wall thickness; i. e., that the tube shall be crushed flat. Others, who are more reasonable, require six times the wall thickness for this distance. It would seem better to strike a mean and specify flattening to four times the wall thickness, which would certainly eliminate any defective material. For very heavy walled tubing,

where the wall thickness is over 10 per cent of the outside diameter of the tube, the distance between plates should be retained as six times the wall thickness.

Bend tests are included in tube specifications because bending into various curves and shapes is necessary for the construction of many parts of the equipment. One company requires that all tubing under three inches outside diameter shall stand being bent cold (under 250 degrees Fahr.) through 90 degrees around a mandrel the diameter of which is five times the nominal outside diameter of the tube. Another company extends this to cover tubing up to 9 inches outside diameter, but reduces the mandrel to 4½ times the outside diameter of the tube. This is a very rigorous requirement, and it is questionable if any large size tubing such as is made by forging and necessarily heavy walled will pass this test. Another company varies the diameter of the mandrel with that of the tube, which is more reasonable. Communications with tube manufacturers develop the information that tubing 2 inches outside diameter and under, may be expected to stand being bent cold (under 250 degrees Fahr.) 90 degrees around a mandrel five times the outside diameter of the tube; and tubing over 2 inches and under 6 inches around a mandrel 7 times its diameter. Tubing larger than 6 inches, which is forged will probably bend 90 degrees around a mandrel 10 times the outside diameter. It would therefore seem desirable to have these figures included in future specifications.

Various limits for maximum and minimum diameter and wall tolerance are given in tubing specifications, but as these fall somewhat outside the scope of metallurgy, they will not be discussed. The tube manufacturers advise on this point that Standard American Society for Testing Materials and American Society of Mechanical Engineers specifications for boiler tubes and seamless pipes can be complied with as regards dimensions.

All tubing should be carefully annealed, this is obviously necessary for the material to pass bend and other ductility tests. After annealing the pickling, sandblasting, rinsing, and nitric acid bath specified for plates should follow.

Castings

Castings are used for flanges, nozzles, valves, pump casings,

pipe fittings such as ells, tees, etc., and parts of equipment not conveniently fabricated by any other means. As castings will be in contact with the gases and liquids generated in the process they should have as closely as possible the same chemical composition as that of plates, tubing, etc. Unfortunately the low carbon of the stainless irons does not lend itself to foundry purposes, for castings of that composition are much addicted to blow holes and porosities. If carbon is raised to 0.30 or 0.35 per cent maximum, a much better foundry metal results. Other elements should be kept as close to the plate and tube analysis as possible, but a slight increase in impurities will probably do no harm. With carbon up to the content mentioned resistance to nitric acid does not seem to be affected. The straight chromium alloys show an extremely coarse grain when cast and are also entirely too hard for machining. A proper annealing treatment will produce reasonable machinability and surprisingly good physical properties although very little grain refinement takes place.

Only one chemical company requires a tensile test on cast material, the following physical properties being required:

Tensile Strength	75,000 pounds per square inch
Yield Point	50 000 pounds per square inch
Elongation in 2 Inches	10 per cent
Reduction of Area	15 per cent

These are well within the limits of the material. Impact strength values are inclined to be uncertain, and are to be reported "as information."

All castings should be thoroughly freed from scale, and here the usual pickling solution will be found somewhat deficient. As with plate, castings should be cleaned both before and after annealing, sandblasting as well as the acid pickle being necessary. The nitric acid dip should follow as with plates, etc.

To insure against porous castings one company specifies, wherever the shape will permit, that all castings be subjected to a 150-pound hydrostatic pressure test. Castings which show leakage under such conditions are rejected. This test should be conducted after all machining operations are finished, although the specifications make no statement on this point.

Welding, plugging, or caulking are usually prohibited. This seems rather a hardship to the casting manufacturer, and insisted on must maintain prices at a high figure. From the standpoint

of corrosive attack welding is undesirable, but there is no legitimate reason why small blow holes and similar defects which do not affect the strength of the casting as a whole, and which occur on surfaces not in contact with corrosive gases or liquids, should not be repaired by a suitable process. It is of course impossible to differentiate sharply on paper what is acceptable in this respect, and what is not. This must be left to the judgment and experience of the inspector.

Forgings

Forgings are used for flanges, pipe fittings, pump shafts and plungers, and other parts of equipment where a better metal than that obtained in castings is desired. Specifications for composition should remain the same as for plates, tubing, rivets, etc., since this analysis may be forged without great difficulty. Important defects to be guarded against are coarse grain structure resulting from too high finishing temperature, insufficient annealing leaving the metal unmachinable, and the usual forging defects such as seams, laps, cracks, etc.

Proper annealing will relieve strains and hardness so that machining may be done with reasonable ease. As with other stainless products a hardness of 200 to 250 Brinell will provide better machinability and threading qualities than when the metal is dead soft.

Since many of the forgings will be small it will be difficult to make tests without destroying the forging. Either a certain number of forgings must be provided with coupons, which will show the quality of the grain structure, or a certain proportion of the total confiscated for purpose of testing. Brinell or Rockwell hardness tests may be made on all forgings and will indicate the success of the annealing operation and the resulting machinability.

Tank Cars

Tentative specifications for stainless iron plates, tubing, castings, etc., for the construction of tank cars for shipment of nitric acid in bulk have been drawn up by the Mechanical Division of the American Railway Association. These follow the duPont specifications and embody the important points discussed in this paper. Fabrication of tank cars should present no greater diffi-

culty than absorption towers or stationary tanks, but because of the rough handling and vibration to which tank cars are subjected in service the greatest precautions must be observed to insure proper strength in the metal, with tightness and stability of riveted points. This is particularly important for the shipment of nitric acid. While leakage would be undesirable in any case, there is danger, other than financial loss, for nitric acid, especially strong acid, is a most powerful oxidizing agent and if brought into contact with organic matter will almost inevitably start a fire.

Chemical compositions for plates, tubing, castings and other parts will naturally be the same as already discussed.

Shipping Drums

It has been customary to ship nitric acid in glass carboys which, because of their fragile nature and the danger of fire from contact of nitric acid and organic matter, cannot be considered ideal containers. Consequently stainless irons have been welcomed by chemical industries as a means of solving this phase of the nitric acid problem as well as that of manufacture.

First experiments were made with drums constructed of the straight iron-chromium alloys. But while these resist attack by the acid in a satisfactory manner, the welds necessary for fabrication of drums were lacking in strength. It was found, in consequence, extremely difficult to produce drums that could be depended upon to meet specifications imposed by the Bureau of Explosives and the Interstate Commerce Commission, which require that there be no leakage after a six foot drop on concrete when 98 per cent filled with water. Various types of drums were constructed; the usual type with welded chime or longitudinal seam, and the two-piece type with equatorial weld. The latter type has proved the better of the two, and passes the Interstate Commerce Commission drop test when dropped on end as required, but if dropped on the side, as might easily happen in handling, the weld gives way.

Recognizing the greater toughness and ductility of welds made on the austenitic chromium-nickel alloys of the "18 and 8" analysis, later experiments have been made with drums constructed from this metal, and these have been found to pass all varieties of the drop test which could be devised.

Drums of various sizes, usually 15, 30, and 55 gallon capacity

have been constructed of No. 14 U. S. Gage sheet, and provided with stainless cast or forged flanges and bungs. While they are admittedly high in cost they should last indefinitely with reasonable care, and this is certainly not true of the highly fragile glass carboys.

Chemical manufacturers are much interested in these drums and have been conducting tests for about a year. There is some question, as was previously noted, regarding resistance of the "18 and 8" analysis to all grades of acid. The chemically pure acid apparently attacks slightly, or at least to such an extent that some discoloration of the acid results after storage in the drums. This is undesirable, and unless means can be found to remedy this, a different composition perhaps—it may not be possible to use drums for this grade of acid. In addition, one or two failures have occurred in the welds after some months in service. But as these drums were among the first made, it is believed that when welding technique is further perfected stainless drums will take the place of the carboys now used, at least for certain grades of acid.

Conclusion

The author is well aware that many points and matters of interest worthy of mention have been passed by. But to have gone fully into all phases of the specification and use of stainless alloys in the nitric acid industry would have extended this discussion beyond all reasonable bounds. Such subjects as size tolerances, number and manner of selection of test specimens, analyses for composition, etc., have been omitted partly for the above reason, but more because decision on such matters should be made only after conference by a committee or group representative of both manufacturers and users of stainless alloys. The proposal, at this time, of the American Society for Testing Materials to organize a committee to consider these alloys is most opportune. There is no reason, except lack of better information, for the wide divergence in existing specifications for these materials. Cooperation in experimental work and preparation of specifications is highly desirable and will be for the benefit of both manufacturer and consumer.

DISCUSSION

Written Discussion: By W. R. Huey, E. I. duPont de Nemours and Company, Wilmington, Del.

In spite of the rapid commercial development of stainless irons in the past five years and the gradually broadening field of use today, there is an unwholesome lack of information about them in the using industries. Where there is any expression of opinion regarding these alloys, it is either foolish optimism or unwarranted pessimism. The latter opinion is usually based upon sad experience with failure of equipment installed unwisely, upon the recommendation of an incompetent laboratory, or a salesman too eager for orders. Unfortunately for the manufacturers, as well as the users, the state of knowledge pertaining to the use of stainless irons is not as highly developed in the alloy steel industry as the broad advertising and sales campaigns now being conducted. We hope that Dr. Mitchell's paper will come to the attention of the chemical industry. It is one more of a meager few published attempts to dispel the cloud of mystery and misinformation that has surrounded these interesting and useful alloys.

Reference has been made indicating that the duPont Company has been associated with the commercial development of stainless iron. We have been actively interested in this development since June 30, 1923, when plant tests were made on the first sample of stainless steel. Experiments were carried out on the first container (110-gallon welded drum) beginning September 18, 1924. In February, 1925, a small ammonia oxidation unit was operating with several pieces of equipment made of stainless iron. A year later several units, made exclusively of about 350 tons of this material, were in operation. Today we have in use or under construction approximately 1200 tons of equipment, some of which is rather intricate in design. This illustrates the rapid development which has made possible an improved and revolutionary process for the manufacture of nitric acid.

The experience gained in working with and using this large amount of stainless iron indicates that if properly handled it is a satisfactory material for construction of equipment to handle nitric acid varying in concentration from 0 to 65 per cent and in temperature up to 110 degrees Cent. Laboratory tests indicate the possibility of broadening the field of use considerably; but certain well defined limits of use and mode of fabrication exist, as indicated by Dr. Mitchell. The stainless irons are far from being the cure-all for all corrosion ills.

There is little published information regarding the effect of various factors in the composition and physical treatment of stainless iron alloys upon the corrosion resistance to nitric acid. We are convinced that information of this nature is of practical value and the duPont Company is proceeding with an extensive investigation to obtain it.

There is no information that will permit foretelling the service life of equipment; and it is doubtful if an accurate determination of the life can be made by other than records of equipment in use. Attempts have been made to estimate the life of equipment from the results of laboratory tests. The error in this mode of reasoning is apparent when it is realized that corrosion is seldom uniform, that a small fraction of an inch wear on an inch thick equipment wall may render it useless and that process conditions can never be duplicated faithfully in the beaker or flask.

Each individual investigator has his own ideas of the best type of laboratory test and the proficiency of the test in approximating the value of the material for service. Generally, insufficient data concerning details of technique, analysis and history of samples, make the results unreliable for the chemical engineer or designer of equipment. Statements are made and conclusions drawn without presentation of data to support them.

In discussing specifications for composition, Dr. Mitchell refers to the work of an investigator* in Germany who concluded that 1 per cent manganese in chromium alloys offsets the beneficial corrosive resistance imparted by 9 per cent chromium. The experiments were made upon alloys prepared under vacuum in an electric furnace and subjected for one hour to hot 10 per cent acids. The results are expressed in grams loss per square decimeter and are as follows:

	Weight Loss Cm./Sq. Dm.				
Alloy	HNO_3	H_2SO_4	HCl	CH_3COOH	H_3PO_4
16% Cr—84% Fe	0	32.0	27.0	0.024	2.440
25% Cr—75% Fe	0	19.0	14.0	0.003	0.003
25% Cr—75% Fe—1% Mn	0	42.9	40.0	0.006	0.004
Decrease Corrosion due to 9% Cr	0	13.0	13.0	0.021	2.437
Increase Corrosion due to 1% Mn	0	10.9	13.0	−0.018	−2.436

The effect of manganese is nil in case of nitric acid, and beneficial in acetic and phosphoric. The results in hydrochloric if considered alone support the conclusion that 1 per cent manganese offsets 9 per cent chromium. Therefore the conclusion is roughly 20 per cent correct. Another misleading statement made in this article is that the loss of 0.1 gram per decimeter in 24 hours would corrode the sheet to 1 millimeter in 800 days. This statement implies that service life can be estimated accurately from laboratory tests. This is typical of the general nature of published information regarding the corrosion of materials.

From the point of view of the user of stainless iron, the time spent in making such experiments as those just referred to is wasted, short though it may be. It is possible to determine comparative values for corrosion resistance in the laboratory if the tests are carried out properly. The complete history of the samples should be known, and preparation of the surface standardized. The test conditions, such as acid concentration, temperature, and time of immersion should be controlled to a nicety. The time of the test should not be less than 96 hours, but preferably longer. No conclusions should be made unless supported by the results from several determinations. Under no condition should life of equipment be predicted from laboratory results.

In discussing the manufacture of tubing and the specifications which should govern it, it is stated that chromium-iron alloys show increased ductility and working qualities when heated to a few hundred degrees and brittleness when cold. It might be of interest to note that our experience with the manufacture of stainless iron tubing indicates this increase in

Chemical and Metallurgical Engineering, Vol. 34, p. 417.

ductility to be apparent only. The fact that successful flattening and flanging tests can be made on tubes only after heating, was found to be caused by the presence of gas in the metal or embrittlement due to pickling. The heating of the tubes evidently removes sufficient of the gas to result in successful tests. Unpickled tubes were bent without failure while pieces from the same tubing after pickling failed unless heated. It was found necessary to boil all small size tubing in water for a few hours at the tube mill to insure success of such operations as rolling into tube sheets. Stainless iron tubes should be thoroughly cleaned by sand blasting and pickling to facilitate the inspection of the surface which is difficult at best.

We cannot agree with Dr. Mitchell's remarks relative to the repairing of blow holes in castings. It is true that this defect is peculiarly prevalent in stainless iron castings, and the covering up of blowholes or other surface defects in castings should not be tolerated. The most generally used method for repairing a casting with blowholes is by means of welding which is likely to lower the corrosion resistance of the metal. Furthermore, the customer is not receiving full value for the metal in the casting when some part of the wall thickness is sacrificed by the presence of a blowhole; for instance—if there is a ¼-inch deep blowhole in a casting having ¾-inch wall thickness, the customer is in reality receiving a casting having ½-inch wall thickness. Castings containing blowholes are likely to be porous also. This condition might not be revealed in pressure tests, due to the fact that on the inside of the casting there is sufficient metal across a gap or pore to hold the pressure, which, when later subjected to the action of acid in service, would last only a short time. This particular pore or gap might lead to the outer surface blowhole, in which case the casting would leak and become worthless. In addition to the existing specifications on castings, the use of X-rays, particularly on castings costly enough to justify such a test, is not outside the realm of consideration.

In discussing shipping drums, Dr. Mitchell states that there is some question regarding resistance of the 18-8 alloy to all grades of acid. In support of this statement, he refers to discoloration of acid after storage in the drums. It is more likely that this discoloration originates from corrosion due to the welds. Our experience has shown that the 18-8 analysis is superior in corrosion resistance in both hot and cold nitric acid and that welding of this as well as other grades of stainless iron is very likely to cause corrosion.

There has been considerable discussion about the merits of welding stainless iron. Ductile welds of high strength have been made upon both the chromium-iron and the chromium-nickel-iron alloys; but for the purpose of the chemical manufacturer, the ductility and strength of the weld are not nearly so important as the corrosion resistance. Welding of either of the above mentioned types of alloy is likely to cause a very severe type of corrosion due to autoelectrolysis. Welding should not be definitely condemned, but at present the art is not sufficiently advanced to insure 100 per cent quality welds. It would seem that there is at present too much of the personal

element in the welding process to permit production of a weld sufficiently similar to the plate to prevent electrolytic corrosion.

Written Discussion: By S. C. Spalding, metallurgist, Halcomb Steel Company, Syracuse, N. Y.

The author of this paper has touched a subject of very timely interest. The consumption of the chromium and nickel-chromium corrosion and heat resisting alloys is increasing by leaps and bounds. New uses for the alloys spring up over night, new fields of usefulness are opened daily. The surface has as yet just been scratched so that one can scarcely dare predict what tomorrow may bring.

The author's point of the 18 per cent chromium, 8 per cent nickel alloy being for many purposes probably a more desirable metal than the straight 18 per cent chromium is well taken. There is no question but that there are many places for the manufacture of stationary apparatus not subjected to high temperatures or pressure where the straight 18 per cent chromium iron is all right. On the other hand when it is a question of the transportation of acid in tank cars, carboys, etc., subject to abusive treatment or work involving high temperatures and pressures, there is no question but that the steel termed by the author 18 and 8 is much superior. The use of this latter steel along with others of the family of "rezistals" first made available in this country by the Crucible Steel Company of America for applications involving high temperatures and pressures would have saved a great deal of unnecessary disappointment resulting from the use of the straight 18 per cent chromium-iron. It is of interest to note that these "rezistal" alloys were first called to the attention of the chemical industries at the second convention of this society held in this same city, Philadelphia, nine years ago. The 18 per cent chromium alloys are quite sensitive to heat. Grossmann in the TRANSACTIONS, Volume 10, showed that if this alloy were heated to temperatures over 1800 degrees Fahr. serious brittleness ensued which could not be eliminated by subsequent heat treatment. This makes it necessary to use great care in the hot working of this alloy and precludes successful welding. The 18 per cent chromium, 8 per cent nickel alloy is free from these objectionable features and still possesses all the useful properties of the straight 18 per cent chromium alloy to even a more marked degree.

A point of importance to the designer contemplating the use of these alloys is that they cannot with the exception of the regular stainless steel or 12 per cent chromium stainless iron be heat treated to give definite and varied physical properties. The physical properties which they may have can be controlled only by the method of working. Cold working tends to raise the physical properties. Heating to increasingly high temperatures tends to soften and lower physical properties, with various desirable maximum temperatures for the different composition alloys. These alloys excepting the 18 per cent chromium-iron can be readily welded either electrically or by gas. The nickel-chromium alloys weld more readily than the straight chromium and those with the higher silicon content being the best in that respect as the silicon seems to act as a self fluxing constituent for the alloy. The use of high silicon content in these chromium-nickel alloys is also the result of

investigations of the Crucible Steel Company of America and since the time nine years ago when they were called to the attention of the industries their superior welding qualities have been demonstrated many times over.

An important point and one on which the author touches rather lightly is the annealing of these alloys with respect to machinability. In general as the annealing temperature is increased, the alloy becomes softer, though not necessarily more machinable. The alloys are not hardenable by quenching so need not be slowly cooled from the annealing heat. It does not seem possible by any treatment to make these alloys what would be called free machining. Even at their best they machine with difficulty and this fact must be recognized in dealing with them. They cannot be cut with the ordinary hack saw but with a high speed hack saw blade and rather slow speed saw fairly well.

Written Discussion: By T. H. Nelson, metallurgist, Conshohocken, Pa.

I have read Dr. Mitchell's paper with interest and only express regret that he did not go in a little deeper into the subject. Dr. Mitchell has left little of a debatable nature, but as a resumé of what has been done up to date the paper is a very useful work. May I respectfully bring up some of the following points:

The future for chromium iron, as seen by Dr. Mitchell, through the chemical industry, I fully endorse and this is encouraging to steel maker and fabricator alike, although I believe the day has dawned for the use of nickel-chromium alloys.

With reference to the various specifications available these seem substantially to be based upon the original duPont work on which I can modestly claim to have done considerable work, plus the knowledge and experience gathered since that time on the variety of equipments that have been built. The question of trade name was never of so little value as in this field. Chemical composition of physical condition is so closely tied up with corrosion resistance that a full knowledge of the metal is essential.

To my mind Dr. Mitchell has missed one of the most important features to the designing engineers and users of chromium alloy and that is the very low elastic limit of some of these metals and the fact that designers in many cases are figuring on the tensile strength and overlooking the low elastic limit. This should be kept in mind when sections are being brought down in size and weight to save initial cost of these somewhat expensive alloys.

I do not quite agree with Dr. Mitchell that carbon under 0.12 per cent avoids air-hardening tendencies. My experience has been that it is always the ratio of carbon to chromium under 16 per cent chromium that is the deciding feature governing the hardening tendencies of the alloy, with silicon as a powerful factor in the 16 per cent area and upwards.

With regard to nickel content, it is to be regretted Dr. Mitchell does not give more data. Will he come out and say definitely what amounts of nickel with the chromium-iron can be regarded safe or otherwise, leaving out, of course, the established nickel-chromium steels.

With regard to fabrication, may I say that with the knowledge we have today I believe that chemical equipment under capable technical supervision can be built in the field.

After so much is being done by some of the conscientious fabricators, the failures still being recorded by some of the smaller concerns who jump into the field with little or no knowledge of the subject is acting as a deterrent on the industry as a whole. I do not wish to retard progress, but can frankly state that most of the troubles experienced today in this direction are due to price, often throwing the work into unskilled hands.

Punching and Shearing. I believe Dr. Mitchell should have gone further in this direction. You have a high priced metal with somewhat high tensile properties, why take unnecessary risks? Only the lighter gages, to my mind, should be punched, say up to ⅜-inch maximum thickness. The very method of manufacture of many parts leaves some strains on these almost untreatable alloys, and where is the sense of trying to punch a 10-foot diameter head flanged and dished, valued approximately at $1200, when by drilling at a little extra cost in proportion, practically all risk is removed? Drilling irregular parts should be strongly advocated.

Preparation of Material. Sandblasting is now acknowledged to be a very valuable acceleration of the pickling operation. I do not agree with Dr. Mitchell on the term "pacify" with regard to the final immersion in nitric acid. I prefer to regard nitric acid as dissolving anything which is solvent, leaving only the iron-chromium alloy as a corrosion resistant surface.

Rivets. On the subject of rivets one could write a book. The specifications and tests mentioned by Dr. Mitchell can be readily met and the riveting temperature reduced to the "ideal," and yet rivet heads will, under certain conditions, come off and, mark this, practically always it is the original head which invariably shows this weakness. The reason for these failures is to be found somewhere through the process of manufacture of the bar in the steel works and the actual making of the rivet and before the finished rivet reaches the fabricator. Cold made rivets from cold drawn bars demand considerable more attention in all operations, particularly in the steel works, and I cannot repeat too strongly that I unhesitatingly stand for cold made rivets driven from a cone to a button head where possible.

A filleted head and countersunk hole was recommended by me in a lecture before the A. S. T. M. in 1926, and I am glad to have Dr. Mitchell support my views in this direction.

Tubing. The embrittling of chromium-iron tubing under certain conditions is unfortunate, but the nickel-chromium analysis will readily take care of this particular field, and chromium-iron tubing should not be prejudiced in other applications on this account.

It is a pity that Dr. Mitchell did not go further and give some data on the heavy sections of plate, the pronounced laminated structure found in same, heat treatments which will give reasonable transverse strength and ductility under such conditions. The advisability from the fabricator's point of view of knowing the transverse and longitudinal direction of rolling when choosing material for intricate parts, so that he might more satisfactorily lay out his work. These and a thousand and one other questions one could ask, and we can only again congratulate Dr. Mitchell on his efforts and regret that either time or opportunity did not allow him to go further.

DR. W. H. HATFIELD: Dr. Mitchell, I should like to congratulate you upon this excellent paper. The subject you have dealt with is one of the greatest importance, and I am driven to contribute to the discussion again simply to have a word on this question of standardization.

Now, personally, I question very much whether the time has come to standardize these materials. The subject is a very new one, we are only at the beginning of it, more and more data and information is coming out, both here and at home, and, therefore, it is really to be deprecated that types should be stereotyped to conform to others. I just submit that view of the matter to the author.

Then I would say this, that I consider it to be the function of any standardizing committee which takes upon itself to deal with these special steels to give authoritative information to the chemical industries as to the corroding media which any particular composition such as the one the author is dealing with will safely withstand. To do that will necessitate somewhat extensive experiments in collaboration with the various manufacturers of this country, and it would be very interesting to us on our side to see what you make of that phase of the thing.

And then, last but not least, it is my opinion that any steelworks, whether it is in England or in America, selling large quantities of these special steels to chemical plant manufacturers, should be prepared in that specification to submit themselves to a corrosion test, a standardized corrosion test, in addition to the ordinary mechanical tests which should be complied with, providing the material is put into a specific condition. Undoubtedly, the condition of these materials should be very carefully studied, because, as the author has mentioned, in fabricating plants you may rivet it, thus you will cold work it to some extent, you may weld it. Now, if you rivet it, you have two conditions, the normal condition and the cold-worked condition, to consider in relation to the chemical processes, and when one bears in mind the effect of variation in the concentration of the corroding media and the effect of temperature, the problem becomes very involved.

Now, as regards welding, unless you are very careful there, you will plunge into a whole sea of troubles, for this reason. You must be very careful that the material that you use for welding, if you use an electrode, is of the same precise composition as the material you are welding.

Again, you must bear in mind that from the weld proper, which, obviously, has been at the liquid temperature of steel, from there inwards into the material, until the heat disappears, you have a whole range of temperatures, which will have a time-temperature effect on the condition of this material.

And that brings me to the only question I shall ask the author and that is this. In the fabrication of this chemical plant over here from the stainless iron, when you have fabricated the plant, you have obviously left in it these various disabilities, which must be partly responsible for the differential results mentioned by the first contributor to the discussion, from the duPont firm. Does the author insist upon these various fabricated parts being heat

treated to place them in a homogeneous, one-phase condition? I would be very much interested if you would answer that question.

DR. W. M. MITCHELL: There have been so many different points brought up and there are so many things that can still be discussed about these interesting alloys that the whole afternoon could well be spent in doing it. I can only attempt to go over a very few of them.

Mr. Huey laments the better development of sales and advertising campaigns than the knowledge of the properties of the alloys themselves. He answers that himself in a subsequent paragraph by noting the unreliability of laboratory tests. So far, unfortunately, the alloys have not been known long enough to establish any very definite results from actual service conditions, and, as Mr. Huey himself states, laboratory tests are not always indicative of what is to be expected. So far it has been necessary to depend on laboratory tests, because that is the only means we have of determining what the alloys can do.

Mr. Huey comments on my reference to the greater ductility of the chormium-iron alloys when heated to a few hundred degrees, and states that this increase in ductility is apparent only and presumably due to removal of pickle brittleness. This has been taken up with the tubing manufacturers who do not agree with Mr. Huey. They advise that ductility is increased in annealed (unpickled) tubing by such heating where the metal showed little ductility when cold. Results were not always consistent, however, for pickled tubing sometimes showed high ductility when cold and heating was not necessary for forming operations. At all events heating to a few hundred degrees is a comparatively simple matter, and it may be well to do this as a matter of precaution,—at least until we have better knowledge of the cause of this apparent increase in ductility.

In regard to the attack on shipping drums made of the 18 per cent chromium 8 per cent nickel analysis by C. P. acid, information has come to hand since my article was written which leads me to believe that this difficulty can be overcome by a suitable heat treatment of the whole drum. It should be possible, since these alloys become austenitic and show a phase change on heating, to eliminate almost entirely the difference in structure of the weld and the adjacent metal. This will lessen the preferential corrosion materially.

Mr. Spalding mentions the 18 per cent chromium and 8 per cent nickel and the "rezistals." I gained the impression from his paper that he considers they belong to the same class of alloys. Unfortunately, I do not agree with this. The "rezistals" are different alloys and contain a higher percentage of silicon, and are made under different patents. The 18 and 8 alloy has somewhat different characteristics. I agree that the high silicon is better for heat resistance and welding, but it does not appear desirable where resistance to nitric acid is concerned.

Mr. Spalding refers to the poor machinability of the stainless alloys. Unfortunately this is true. But it has been my experience that the alloys machine more easily when somewhat hard, as by cold working, than when annealed dead soft. A straight iron-chromium stainless alloy with Brinell

of 250-300, or even higher, is more easily machined than one with Brinell of 150, as obtained by full annealing. This is not true of the "18-8" austenitic chromium-nickels, which are always hard to machine, and which can be cut successfully only with properly sharpened tools at a slow speed with moderately heavy cut.

Mr. Nelson brings up some very interesting points and questions. The only thing I can say is, the limitations of space in my paper prevented me from including a great many other things that are worthy of discussion. I feel that many of these points are at present still more or less controversial and should be discussed in a committee, as I have suggested. One or two comments, nevertheless, are in order.

Mr. Nelson questions my statement that low carbon will "avoid air hardening tendency". Perhaps the choice of the word "avoid" was unfortunate, and "lessen" would have been more correct. We are discussing alloys with 16 per cent chromium minimum with carbon under 0.12 per cent and it is virtually impossible to harden this alloy above 200 to 220 Brinell, no matter what the heat treatment. This can scarcely be called a hard metal. The low chromium stainless iron (12 to 14 per cent chromium) are, however, a different sort of alloy and will harden readily, even with carbon around 0.12 per cent, to 400 Brinell or even higher.

I am glad Mr. Nelson has mentioned drilling of rivet holes instead of punching. I heartily agree that it is poor economy to risk costly dished heads or other pieces of equipment merely to save the small extra cost of drilling.

Just what effect is actually produced by the final nitric acid dip after pickling is somewhat uncertain. Doubtless it removes all free iron and scale from the surface of the metal. Presumably it also produces a very thin, tightly adherent film of oxide on the chromium or chromium-iron solid solution at the metal surface. This film is not soluble in the acid and hence prevents further action or attack. I believe it is customary to consider phenomenon of this sort as "pacification" of the metal.

Mr. Nelson asks regarding the permissible nickel content in the nickel-chromium stainless alloys. There appears to be no consistent information available on this subject. Nickel-chromium alloys with 16 to 20 per cent chromium seem to be unattacked by cold nitric acid with nickel content all the way up to that of alloys of the nichrome class. Hot acid, however, rapidly attacks the high nickel alloys. It is not a question of how much nickel may be used, but of how little is necessary to give a workable, ductile alloy of the austenitic type. Why increase nickel content when it merely increases the cost?

Dr. Hatfield raises some very interesting points. The difficulty of welding is one of them. As I mentioned in my paper, I think it will be only a short time before the 18 per cent chromium-8 per cent nickel analysis will, in a great measure, supplant the straight chromium irons. The chromium-nickel is a very much more fool-proof metal, it is easier handled in mill operations, has the advantage of being very much more easily welded, the welds being ductile to a considerable degree, and tough. It is possible by heat treatment of the welds, or of the equipment, providing its shape does not prohibit it, to remove

considerable of the difference in structure between the weld and the adjacent metal.

Dr. Hatfield asks regarding heat treating of fabricated structures to render the metal homogeneous. This is obviously most desirable and should even be insisted on, but, unfortunately, we cannot heat treat a nitric acid tower ten feet in diameter and fifty-two feet long. That is at present beyond the limit of our ability. If the carbon is maintained sufficiently low, we avoid considerable of the difficulty caused through cold working, and until we are better equipped to produce carbon-free alloys, we must be forced to take the metal as it comes and to accept the consequences from the limitations of our ability to heat treat after fabrication.

W. E. GRIFFITHS: Dr. Mitchell calls attention in his paper to the difference in opinion between the manufacturer and the user of castings with respect to the welding of defective castings. At the present time the consumers of stainless steel castings will not permit welding to be done upon the castings. There is no doubt that this is an unnecessary hardship on the casting manufacturer. I have seen castings with small defects which could readily have been made usable and saved a good deal of time with respect to furnishing the customer with a casting were the welding of minor defects permitted. In other words, to make castings over again necessitates quite a bit of time, as well as additional cost. I think that this point should be gone into in detail with respect to amending the specifications as regards welding or repairing of slightly defective castings.

The recent trend on the part of the users of stainless steel castings is to require a lower carbon content. This, I believe, is due to the fact that a good many of the acid resistance tests are made on rolled products. When making low carbon castings you must, necessarily, when you have low carbon, have a large grain size, if you do not use any other alloying element. This means that you do not get as strong a casting as you do when you have a slightly higher carbon content, due to the fine grain size which accompanies higher carbon. When I say high carbon, I mean about 0.25 per cent. There are recent inquiries for castings with 0.10 per cent carbon. Now, casting manufacturers can make 0.10 per cent carbon, but these castings must necessarily have a large grain size, which I do not believe is a good thing. With 17 to 19 per cent chromium, as most of these castings run, and 0.10 per cent carbon, the castings are not subject to grain refinement by heat treatment. The original grain size of rolling stock is not so important, as in the working processes the grain size is materially reduced.

Dr. Mitchell's presentation has been very interesting and I have enjoyed listening to it.

JEROME STRAUSS: I would like to second some of the remarks made by Mr. Nelson a few moments ago to the effect that I firmly believe that sufficient knowledge is available concerning manufacture and fabrication of these chromium irons to make them fully commercially usable, but most of the failures, at least of late, have been largely due to insufficient dissemination of knowledge and, sometimes, insufficient and incompetent supervision, not only of the manufacturing, but also of the fabricating operations.

I would like also to comment upon Dr. Hatfield's remarks concerning specifications. One must have specifications to effectively buy, and if any specification is made by those who understand the details of the art and is revised with sufficient frequency to keep the specification abreast of manufacturing advances, it is a distinct utility and not a detriment.

Also, in reference to the subject matter of the paper, while fully agreeing that for some of the operations in nitric acid manufacture, the high chromium steels are fully justified and, perhaps, economically necessary, there are certain operations, notably the combination of the nitrogen and hydrogen to produce ammonia, wherein the masses of metal that are required for the reaction chamber would not only be highly uneconomical in a high chromium steel, but also are beyond the present limitations of the art in the manufacture of such steel. For this work the earlier carbon steels have been supplanted by the low alloy steels, particularly those containing chromium of about the same order of magnitude as that contained in the steels which were discussed by Mr. Demmler this morning, along with smaller proportions of other alloying elements. These can be produced successfully in sufficiently large masses to meet the requirements and have been giving exceptional service. The structure to which this comment applies are large reaction chambers with walls of the order of four to five inches thick.

T. H. NELSON: One of the previous questions raised a point on which I can, perhaps, throw a little light. That was the subject of castings. It so happens that I have a substantial interest in a foundry engaged entirely on chromium-iron castings and alloys. The previous speaker said he did not see why in some cases welding could not be permitted. While it would affect my pocketbook very favorably to support his view, I can honestly say that I do not feel that it is justified. I would much prefer to see such castings caulked rather than welded, which brings up the point that the graduation from the welded spot (irrespective of the tendency to develop radial cracks) and the various physical conditions of the material from the weld outward are serious points of corrosive attack.

There is little use denying that chromium-iron castings have been a weak link in the chain of supplies of chromium-iron equipment and these unfortunate failures have created in the minds of users a very unfavorable opinion of chromium-iron castings. As soon, however, as we realized the fallacy of attempting to duplicate the chemical analysis of a forged bar or a rolled bar or plate in a casting, then we began to really make headway. It is a story in itself as to whether green sand or dry sand molds produce the best results.

But I do want to hold out the hope, that whatever may have happened in the chromium-iron casting field in the past, the chromium-iron castings available today from the various reputable manufacturers are a distinct and advanced step over those obtainable two years ago. I feel the carbon range can justifiably go up to 0.35 per cent with material of, say, 18 to 20 per cent chromium, that with 0.35 per cent carbon the corrosion resistance is all that can be desired, the fluidity of the liquid metal is such that a reasonably good casting can be obtained, and the art itself has advanced

to the point where we can get a fully deoxidized metal when poured into suitably prepared molds, a metal which will give a casting, not 100 per cent sound, because the casting industry even in better known metals is not 100 per cent, but a casting which is comparable in number of sound castings to that of gray iron or steel.

So much trouble has been experienced that many manufacturers today are leaving castings for the forged field, at considerable expense and considerable trouble. To those people I would say they can conscientiously consider coming back, because there are as many inherent troubles today in forgings, if not more, than there are in good castings from a good source of supply.

DR. W. M. MITCHELL: In regard to castings, my paper reads: "From the standpoint of corrosive attack, welding is undesirable, but there is no legitimate reason why small blowholes and similar defects which do not affect the strength of the casting as a whole, and which occur on surfaces not in contact with corrosive gases or liquids, should not be repaired by a suitable process. It is, of course, impossible to differentiate sharply on paper what is acceptable in this respect and what is not. This must be left to the judgment and experience of the inspector."

I think I left the gate open sufficiently wide for the chemical companies to be pessimistic and for the stainless iron foundries to be optimistic, and, as I say, much depends upon the nature of the defect. It is a matter which must be left to the judgment of the inspector. I think it is quite possible to salvage a good many castings that might be thrown out if a hard and fast rule were established that no welding and no caulking should be allowed. That simply works a hardship on the manufacturer and increases the cost of the casting, and chemical companies now proclaim strongly against the present high cost of the materials. It is obviously best to reduce the cost wherever that is possible with due regard to the other conditions involved.

As regards the carbon content of the castings, the reason for the desirability of low carbon content is to reduce the possibility of electrolytic action between the casting itself and the adjacent metal, which presumably will take place if this is a rolled structure. Since it is impossible to produce altogether good castings of low carbon, it is necessary to raise the carbon somewhat, and in this way the possibility of producing poor castings is somewhat avoided.

FURTHER OBSERVATIONS ON THE MICROSTRUCTURE OF MARTENSITE

By Francis F. Lucas

Abstract

This paper is a further contribution on the microstructure of martensite. It describes a number of quenching and tempering experiments in which commercial high quality tool steels were used. Representative structures found in the quenched and various tempered conditions are illustrated and discussed.

Introduction

IN 1924, the writer presented before this Society, a preliminary paper on the microstructure of austenite and martensite[1]. In the experiments described in that paper, it was desired to deal with individual martensitic needles in a field of austenite so that some conclusions, if possible, might be reached as to the probable nature of the constituent martensite. A special iron-carbon alloy was prepared and, after suitable treatments, specimens were quenched from a very high temperature in an ice and brine solution. The specimens were then examined by high-power methods. Representative photomicrographs illustrating typical structures as revealed by nitric acid and picric acid etchings and also by treatment in boiling sodium picrate were published.

The tentative conclusions reached by the experiments described might be summarized as below:

1. A martensitic needle is a decomposition along the octahedral crystallographic planes of austenite.
2. A martensitic needle is confined to an area of uniformly oriented austenite; i.e., a needle never crosses a grain boundary or a twinning plane.

[1]The figures appearing in parentheses refer to the bibliography appended to this paper.

A paper presented before the tenth annual convention of the society held in Philadelphia, October 8 to 12, 1928. The author, Francis F. Lucas, a member of the society, is associated with the research laboratories of Bell telephone Laboratories, New York City. Manuscript received Aug. 6, 1928.

3. Martensitic needles darken with sodium picrate, an etch which selects iron carbide. (They also etch with nitric or picric acid, reagents which do not stain or attack iron carbide.)
4. Martensitic needles have a mottled granular appearance. Oftentimes, a line structure is found and occasionally needles are found which exhibit multiple twinning.
5. A martensitic needle is an aggregate and not a solid solution and it indicates a decomposition of the austenite, probably to alpha iron and iron carbide highly dispersed.

It is the object of this paper to present some further evidence on the nature of martensite and its mode of formation and decomposition by tempering. These observations have been briefly mentioned in two preceding papers (2), (3) but will be more fully dealt with here.

Many improvements in the technique of preparing specimens for high-power metallography have been developed since the early work and new optical systems such as the mono-brom-napthalene objective and the ultra-violet microscope have been developed to a state of usefulness in this important field.

At the time of the early paper, it was thought that all reasonable precautions had been exercised to insure that the specimens were not tempered during the work of preparing them for metallographic examination. It is now known that the surface structures were slightly tempered, but the conclusions reached in the paper are not changed except that they relate to specimens slightly tempered. If hardened and tempered structures are to be examined by high-power methods, and if the results are to be of scientific value so far as the "as quenched" condition of the specimens is concerned, then there must be some surety that hardened specimens can be prepared for examination without causing any appreciable change in the surface structure.

Much care was devoted to the development of a polishing technique which would satisfy the conditions, and the results shown at this time are believed to represent practically no tempering by the preparation work. As a check, one of the identical specimens reported on in the preliminary paper was re-prepared by the improved methods, and typical structures have been illustrated (3). Instead of the needles being mottled uniformly over

the entire surface as was found to be the case in the original work (1) (for example, see Figs. 8, 9 and 10 of the early paper referred to above), the needles are either white or exhibit a delicate line structure traceable to the octahedral planes. The lines are light brown as seen through the microscope and evidently manifest a state similar to the fully mottled needles, but less advanced.

A martensitic needle generally appears brown under the microscope but several writers have described a "white martensite". That is, the needle, instead of appearing brown, is white. The differences can now be explained on the basis of observed facts.

Methods Employed

A number of steels from different manufacturers were examined and heat treated preliminarily for the purpose of selecting from those examined, one which was uniform and homogeneous throughout. The object was to select a steel which was free from segregations of any kind and with few solid non-metallic inclusions.

For the purpose of the experiments to be described, a high quality Swedish tool steel was selected. It was in the form of a ⅝-inch octagonal bar. The chemical composition is as follows:

	Per Cent
Carbon	0.90
Manganese	0.19
Phosphorus	0.037
Sulphur	0.005
Silicon	0.032

A number of pieces about ⅛-inch thick were cut from this rod and one face on each specimen was ground flat and partially prepared for microscopic examination prior to heat treatment. The opposite face of each specimen was stamped with a number. The specimens were then heated in a vacuum furnace for three hours at 1000 degrees Cent. (1832 degrees Fahr.) and quickly quenched in an ice and brine solution.

Several specimens were prepared for examination on the previously ground surfaces. Others were cautiously sectioned so that it might be assured that the structures appearing on the ground face were typical of those found throughout the interior. Hardness readings indicated that decarburization had not taken place so that a double check testified as to the uniformity of the specimens.

FIG. 1—WHITE MARTENSITE
MAGNIFICATION × 3500

Martensitic needles usually appear brown in a white field. Some writers have spoken of "white martensite" in which case the reverse is true; the needles are white and the field dark.

The white areas or "white martensitic needles" indicate freedom from tempering. They probably are extremely hard and they are resistant to etching. Note very fine polishing scratches in the white areas: also that the fillings have dissolved away by the etching—not the needles. The fine scratches were resolved photographically. They were not visible to the eye. The diagonal black line is a quenching crack.

FIG. 2—WHITE MARTENSITE
MAGNIFICATION × 3500

When a specimen similar to the one illustrated in Fig. 1 is etched for a long period of time in nitric acid solution, the fillings are dissolved away, leaving the needle-like areas standing in relief. The white areas develop cubic etching pits and, sometimes, a line structure indicative of the cleavage planes. Thus we learn that untempered "white martensite" has some of the characteristics of a solid solution.

This photograph is from a specimen of the same steel illustrated in Fig. 1 and which had identical heat treatment. The specimen probably was not tempered at all in the preparation work. The Rockwell hardness was C65-68.

Having exercised reasonable precautions to see that the specimens were all substantially identical, successive specimens were tempered by increments of 100 degrees from 100 to 600 degrees Cent. (212 to 1112 degrees Fahr.) and a final one at 650 degrees Cent. (1202 degrees Fahr.). There was then available for microscopic study, a series of identical specimens, some in the "as quenched" condition and others quenched and tempered as indicated above. The average Rockwell hardness readings of the specimens in this particular series are shown in Table I.

Table I
Rockwell Hardness of Specimens

No.	Specimen Tempered at	Rockwell Hardness As Quenched	Rockwell Hardness After Tempering
25		C 68	
31		C 64	
26		C 65	
27		C 64	
36	100° C.	C 64	C 64
30	200° C.	C 68	C 65
29	300° C.	C 66	C 54
32	400° C.	C 67	C 49
33	500° C.	C 66	C 41
34	600° C.	C 67	C 32
35	650° C.	C 66	C 28

It is the object of this paper to amplify what has already been stated about these experiments and to illustrate the typical structural changes which accompany tempering treatments in hardened steel of this particular composition.

High-power microscopic examination of the specimens in the "as quenched" condition does not reveal a felted mass of brown needles when the specimens are etched in the usual way. That is, if all tempering action, surface or otherwise, is avoided, the needles are not brown but they are white and, contrary to what one might expect, it is the interspaces or fillings between needles which etch or dissolve away. Thus we learn that the needle-like forms are more resistant to etching than the matrix in which they are found.

If a photograph of a specimen of this kind is examined closely, faint polishing scratches are visible in the white needles, but disappear in the fillings. A scratch will appear in one needle—disappear in the filling adjoining and reappear in the next needle-

like form. Obviously, the etching action went below the faint scratches and dissolved away the metal in the interspaces or fillings.

It should be understood that the polishing scratches alluded to are not coarse ones but they are so delicate that their presence remained undetected except by photographic means. The eye could not perceive any suggestion of scratches when the specimens were examined visually through the microscope or when the details were studied closely on the clear glass focusing screen with a focusing glass, a deep blue filter having been inserted in the illuminating train.

One of the difficulties, thus far not fully solved, is to prepare hardened steel specimens of this sort so that these faint polishing scratches will not be present. The advances in photographic technique have progressed more rapidly than the ability to prepare specimens satisfactorily.

Not all of the needle forms are clear white. Some are slightly mottled and occasionally, needles are found which turn brown before the interspaces start to develop. These are usually localized in some small area of the surface. Possibly they represent a zone in the specimen which did not cool rapidly as compared with the rest of the specimen. It also is possible that they may indicate localized tempering in the preparation work, but this is thought not to be the case. By the time the interspaces start to etch, these brown needles are quite dark. Occasionally, needles are found with a dark interior and a white exterior, showing that the two forms are related.

In this paper, it is not the intention to discuss in full detail the constituent troostite. Hardened steel specimens, such as those used in this study contain much troostite mostly in very small nodules or particles. At this time, we are particularly concerned with what happens to the needle forms when the steel is tempered. However, the fact should not be overlooked that troostite is always present.

When an "as quenched" specimen is deliberately tempered on the surface by abrasion such as by grinding on a surface grinder or by rather heavy abrasion on a dry paper, "white martensite" is no longer found. Instead, the typical brown needles occur on etching and the matrix is then white. One might regard this matrix as austenite but this is not correct because, before the

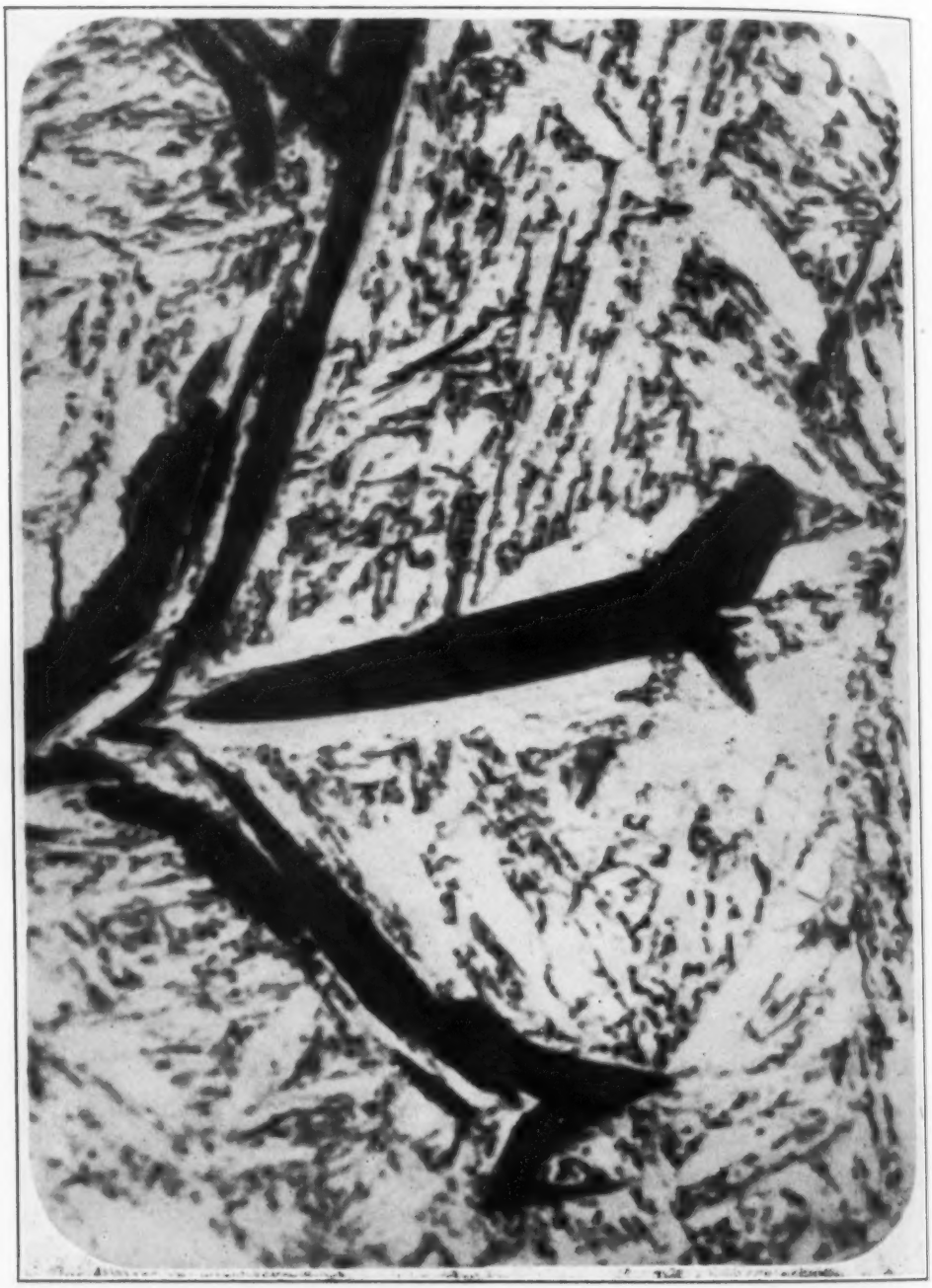

FIG. 3—WHITE MARTENSITE AND BROWN MARTENSITE ARE RELATED
MAGNIFICATION × 3500

This photomicrograph is from a specimen of S.A.E. 1090 steel, heated in vacuum to 1000 degrees Cent. for 30 minutes and quenched in ice and brine at 5½ degrees Cent. The Rockwell hardness of the specimen after heat treatment was C60.

The specimen probably was not tempered at all in the preparation work, but a slightly tempered zone resulted in the specimen from the quenching. This field shows the white martensite with the interspaces or fillings dissolved away by the etching. The central parts of several white needles appear black. The black areas were very dark brown when viewed visually through the microscope.

FIG. 4—SPECIMEN NO. 31—"AS QUENCHED CONDITION"

MAGNIFICATION × 3500

Rockwell Hardness C64-65

A typical view of the "White Martensite" or "Residuals" in Specimen No. 31 described in the test. The white needles are probably free from tempering. The fillings or interspaces have etched away. The broad dark line is a quenching crack.

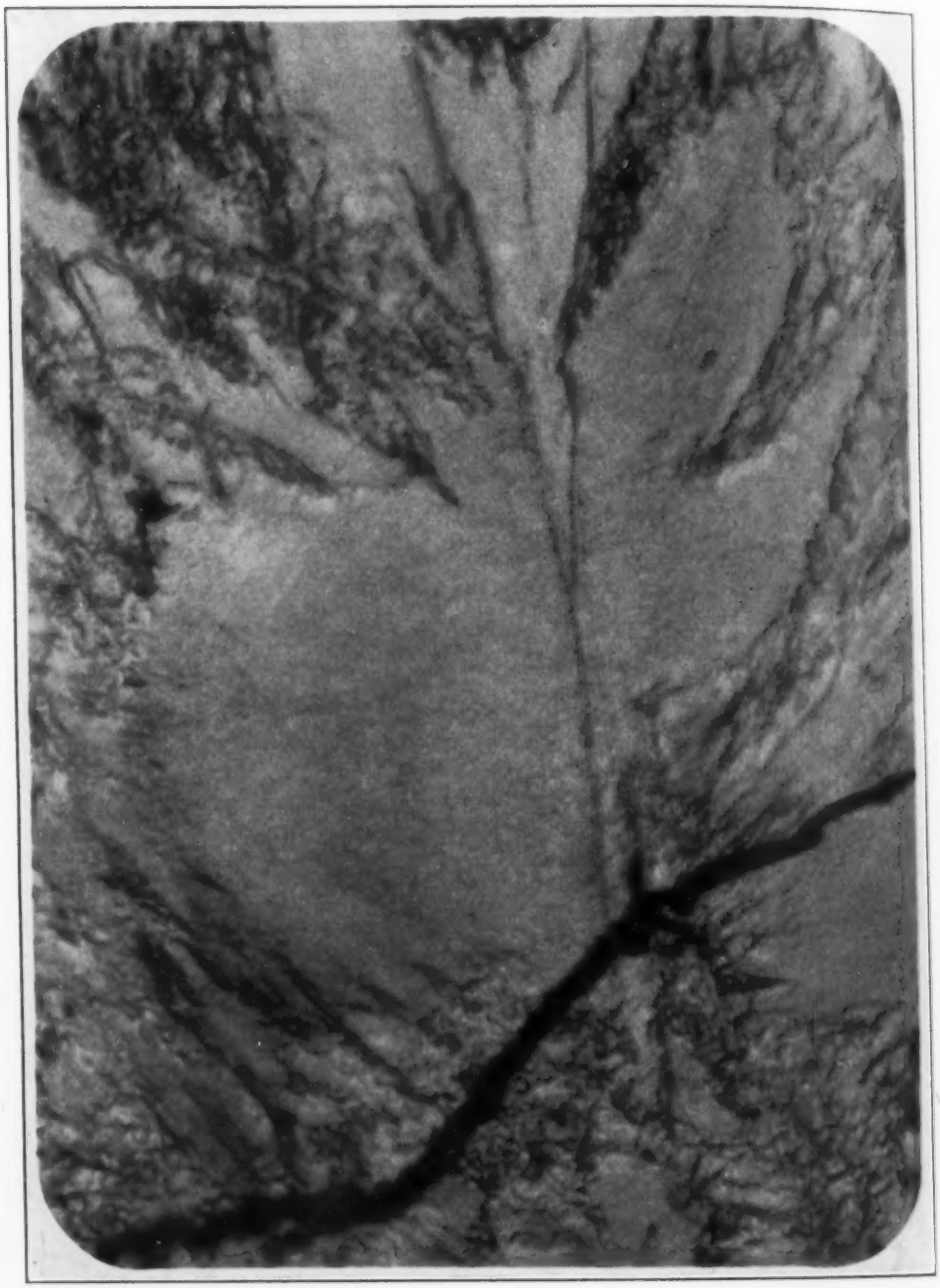

FIG. 5—SPECIMEN NO. 31—"AS QUENCHED CONDITION"
MAGNIFICATION × 3500
Rockwell Hardness C64-65

A "White Martensitic" or "Residual" area which shows some evidences of tempering. It is mottled slightly and something has precipitated in very small particles. The broad black line is a quenching crack.

FIG. 6—SPECIMEN NO. 26—"AS QUENCHED CONDITION"
WHITE MARTENSITE PARTIALLY TEMPERED

MAGNIFICATION × 3500

Rockwell Hardness C65-66

A field of white martensite in which one large needle is tempered at one end and only partially so at the other. Note the shading from the tempered to the less tempered zone. In the slightly tempered area, the individual particles which have precipitated are nearly resolved. Obviously, as the needle tempers, it loses the solid solution characteristics shown in Figs. 1 and 2 and becomes a coarser aggregate.

abrasion or surface tempering took place, the matrix etched more rapidly than the white needles, which now etch more rapidly and appear brown. Etching effects, therefore, are relative.

If an "as quenched" specimen is etched for a long period of time so that the fillings are dissolved away to an appreciable depth, the true white needles exhibit some of the characteristics of solid solutions. Small cubic etching patterns develop and, in some cases, a line structure is revealed. The fillings or interspaces, which for the most part are dark, now reveal a great many little white areas or white inclusions standing in relief which apparently react the same as the larger white needles and probably are identical in nature. That is, white martensite is a state of the metal and not a form or pattern. It may occur in large areas, needle-like in form or otherwise, or it may occur in very small particles.

The specimens quenched and tempered at 100 degrees Cent. undergo a change. The hardness change appears not to be appreciable, but structurally, the needles start to turn brown and show mottling much as the specimen which was deliberately surface-tempered by abrasion.

Tempered at 200 degrees Cent. (392 degrees Fahr.), the specimen does show a falling off in hardness, and its structure becomes darker; there is a decided falling off in contrast between the matrix and the needle forms.

Tempered at 300 degrees Cent. (572 degrees Fahr.), the structure almost defies resolution. The matrix and the needles now etch about the same. As a result, contrast is lacking.

Tempered at 400 degrees Cent. (752 degrees Fahr.), the condition is much the same except that the structure is more granular appearing. It is obviously an aggregate. Contrast is commencing to improve and small particles are resolved.

At 500 degrees Cent. (932 degrees Fahr.), the particles are well within range of vision.

Tempered at 600 degrees Cent. (1112 degrees Fahr.), the particles are considerably larger. If these specimens are etched with sodium picrate, the particles are dark and the field is white. Obviously, the particles are iron carbide.

At 650 degrees Cent. (1202 degrees Fahr.), or just below the critical range, the carbides have coalesced to form larger particles and the structure approaches spheroidized cementite.

Throughout all of these temperings, the old needle and nodule outlines persist. At the higher temperings, the borders are marked by carbides and very small carbides appear throughout the interior.

Discussion

What is the meaning of these observed changes? The experiment starts with the steel in the austenitic condition and all carbides have been absorbed. The specimens are very quickly quenched and white needles are found which comprise a large proportion of the structure. Obviously, the needles must be hard—probably they are extremely hard.

From the work of Mathews (4), (5), Bain (6), Enlund (7) and others, it is known that some austenite is retained in the "as quenched" condition and that it persists for a time.

The white needles on slight provocation, so far as tempering is concerned, develop a mottled structure, i.e., they start to precipitate something. This something we identify later as carbide. If the "as quenched" specimens are treated with boiling sodium picrate, they obviously are no longer in the "as quenched" condition but in the "as quenched and tempered at 100 degrees Cent. (212 degrees Fahr.)" condition. Whether carbide particles are present in the "white martensite" of the "as quenched" specimens is not known. A satisfactory means was not available for selecting exceedingly fine carbide precipitates without tempering the specimens in the slightest. It is true that when one of the present series of "as quenched" specimens is treated with sodium picrate, the needles stain dark. This response to sodium picrate by individual needles was reported in the preliminary paper.

Let us consider some of the structural possibilities of the white martensitic areas. It seems they must represent freshly quenched martensite. The white areas probably are the first decomposition product of austenite. These steels are known to contain some retained austenite, so that the body or matrix of the white forms may be austenite not completely transformed to ferrite. Some austenite remains, not a great deal, but at least an appreciable percentage. What has happened to the carbon or carbide? Some believe (8) it is taken into solid solution by the alpha iron. There is a step here which is important. Does the carbon or carbide step out of the gamma iron lattice and into the

FIG. 7—SPECIMEN NO. 27—"AS QUENCHED CONDITION" AND LOCALLY TEMPERED BY SURFACE GRINDING

MAGNIFICATION × 3500

Rockwell Hardness C64-65

The surface of the specimen was ground on a surface grinder. No evidence of heating could be detected by the hand, yet the surface was tempered slightly. Practically all of the "white martensite" has turned brown and appears mottled.

alpha iron lattice, using the alpha iron as a temporary abode, or does it lie atomically dispersed with the alpha iron, the two forming a very fine aggregate? Such an aggregate probably would appear as a solid solution even under the conditions of maximum microscopic resolution.

Under the latter condition, there would prevail probably at the first instant of decomposition of the austenite, many small nuclei of decomposition, each indicating associated particles of carbide and alpha iron. This assumes that if carbon is held in solid solution in the gamma iron, it combines when released with alpha iron to form the carbide.

Also, what happens to the gamma iron? Are whole blocks of it transformed instantly to whole blocks of ferrite, or does the transformation progress atomistically more like a precipitation wave than a mass transformation? There seems to be little evidence to support the block idea.

There is this to be said on the subject: Specimens of hardened steel are largely mixtures of the things which metallographers call martensite and troostite. A martensitic steel contains innumerable particles of troostite—some relatively large nodules—some moderately small, say a few hundred thousandths of an inch in diameter and from this, they decrease in size to the vanishing point of resolution. This vanishing point is somewhere around two hundred atom diameters by present methods.

The moderately small particles of troostite have been studied very thoroughly and very carefully in the past few years. They have been photographed in sections showing radial grains about a nucleus of growth. The radial grains are sometimes fully stratified pearlite and sometimes they are barely resolvable as an aggregate. The intermediate stages have been photographed and it is the opinion, backed by a good deal of evidence, that troostite as we know it in the "as quenched" condition is an aggregate of alpha iron and iron carbide. The very small particles of troostite look and react like tempered martensite—in other words, small brown particles which have a granular structure and which etch more rapidly than the white martensitic needles. They stain with sodium picrate, showing carbide is present. (Here it must be kept in mind that boiling sodium picrate is used, hence the tempering temperature is about 100 degrees Cent.). The interspaces or

FIG. 8—SPECIMEN NO. 36—"AS QUENCHED CONDITION AND TEMPERED AT 100 DEGREES CENT."

MAGNIFICATION × 3500

Rockwell Hardness C64

Tempering at 100 degrees Cent. resulted in no appreciable change in the hardness, but much of the "white martensite" turned brown. This field probably represents the maximum change effected by the tempering. This figure has a striking resemblance to Fig. 7.

fillings which dissolve away first in an "as quenched" specimen containing white martensite are believed to be a very fine aggregate of alpha iron and iron carbide particles but a coarser aggregate of the two than that which prevails in the "white martensite" areas.

The evidence points to the fact that in hardened steel, one deals with mixtures of three things:

1. Gamma iron, the original matrix
2. Iron carbide, which is precipitated or which forms at first in particle size below present methods of resolution as the gamma iron changes to alpha iron
3. Alpha iron

At the instant of quenching the steel is in the austenitic condition with the the carbon or carbide in solid solution. During quenching exceedingly fine carbides are precipitated as the gamma iron transforms to alpha iron. In the freshly quenched martensitic state (white martensite) the carbides may be so small as to be quite invisible by present microscopic technique but when the steel is even slightly tempered they immediately manifest themselves. These very fine carbides must be intimately associated and intermixed with the freshly transformed alpha iron particles.

Dr. Jeffries (8), (9) believes these small alpha iron particles to be grains. At any rate, they must be alpha iron units and they must be closely associated with very small carbide units so that it is undoubtedly true that in the early stages of martensitic formation (white martensite), there are many very small grains of alpha iron. They may or may not have the carbide in solid solution. This seems to be a matter of speculation, reasoning or opinion.

If this small grain idea is correct, there must be hundreds of thousands or millions of grains per square millimeter. It is to this grain refinement that Jeffries attributes the great hardness but he also believes the presence of the fine carbide particles to be a contributing source of hardness.

Professor Sauveur (8) pictures the unit precipitated as troostite in austenite. This unit (troostite) may be alpha iron holding carbide in solid solution or it may be practically an atomic aggregate of the two. The combination is not stable in this condition.

Nodular troostite (10) shows an orderly arrangement of

FIG. 9—SPECIMEN NO. 30—"AS QUENCHED AND TEMPERED AT 200 DEGREES CENT."

MAGNIFICATION × 3500

Rockwell Hardness C65

After tempering at 200 degrees Cent. (392 degrees Fahr.) there is a falling off of about 3 or 4 points in hardness. The specimen etches readily. The needle structure and the background both etch. Occasionally, "white martensitic" needles partially tempered are still found, but generally the needles have a coarse granular appearance. Contrast between the needle structure and the matrix has diminished.

FIG. 10—SPECIMEN NO. 29—"AS QUENCHED AND TEMPERED AT 300 DEGREES CENT. (572 DEGREES FAHR.)"
MAGNIFICATION × 3500
Rockwell Hardness C54

Tempering at 300 degrees Cent. (572 degrees Fahr.) causes a falling off in hardness of about 12 points. The specimen now etches very readily and the needles and the matrix etch about the same, so that little contrast is developed. The photographs seem to indicate that the structure is a very fine aggregate in which the particles are just on the verge of resolution. The structure seems to be so uniform throughout that with present known methods of etching, contrast cannot be developed between constituents.

FIG. 11—SPECIMEN NO. 32—"AS QUENCHED AND TEMPERED AT 400 DEGREES CENT. (752 DEGREES FAHR.)"

MAGNIFICATION × 3500

Rockwell Hardness C49

Tempering at 400 degrees Cent. (752 degrees Fahr.) has resulted in a decrease in hardness of about 15 points. This specimen etches about the same as Specimen No. 29 illustrated by Fig. 10. It will be observed, however, that contrast is developing now and that the structure is obviously a coarser aggregate than that shown in Fig. 10. It is easy to make out individual particles in the field.

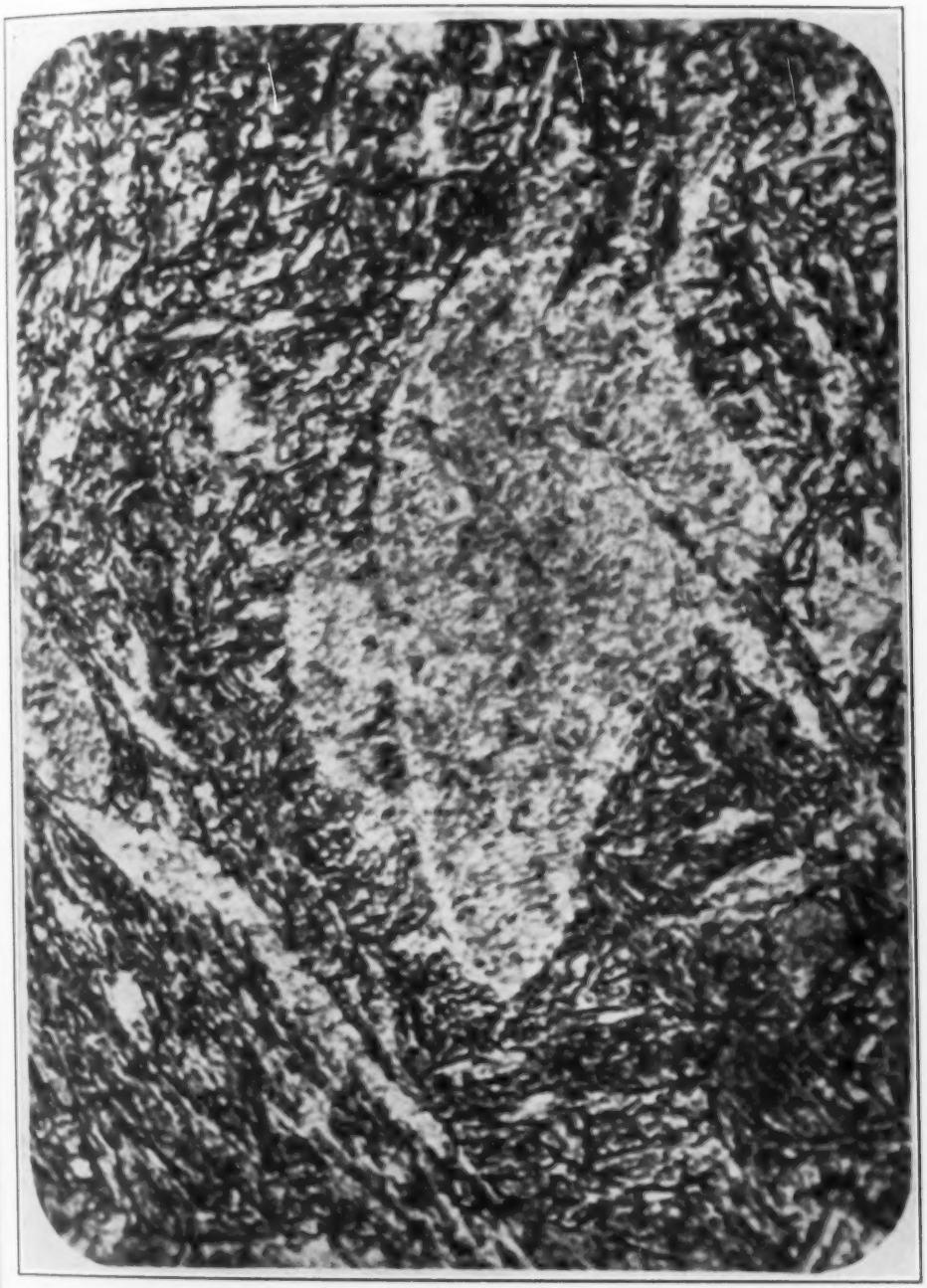

FIG. 12—SPECIMEN NO. 33—"AS QUENCHED AND TEMPERED AT 500 DEGREES CENT. (932 DEGREES FAHR.)"

MAGNIFICATION × 3500

Rockwell Hardness C41

Tempered at 500 degrees Cent. (932 degrees Fahr.), the hardness falls off about 25 points. Contrast has improved in the structure. Many particles in the old "white martensitic" areas are plainly visible.

crystalline growth about a nucleus, indicating probably a re-orientation of the freshly transformed alpha iron particles about an inclusion or a void; or along a grain boundary or a crystallographic plane. The carbide collects in very thin plates forming a laminated or sandwich structure with the ferrite. Thus pearlite is formed under one combination of circumstances. These observations are a matter of photographic record.

The particular microscopic pattern which results, is only a manifestation in visual form of the way in which the transformations took place. The pattern gives some idea of the rapidity with which the changes occurred. If very rapid, the microscopic pattern is found to be mostly needle-like but if less rapid, nodules in abundance develop.

What is important is the proportion of ultimate constituents which are present and their particle size. These are gamma iron, alpha iron and iron carbide. The two latter constituents when closely associated are troostite.

Professor Honda (11) believes that martensite forms first and troostite develops secondly, replacing the martensite. This probably is correct but it hinges on whether we deal with the ultimate structural nature of the constituents and not with their outward forms. No tangible microscopic evidence is apparent to justify the conclusion that needles form first and then in some way are replaced by nodules in full or in part. For one thing, if this were true, nodules would be found with partly absorbed or transformed needle-like crystals sticking out about their outlines. This is never the case.

The white martensitic areas may be regarded as "residuals"; areas which have lagged behind a bit in the transformation. When the specimen is slightly tempered, the transformation is resumed and proceeds with great rapidity as though the "white martensite" areas were in a supersaturated state. It seems to require only a moderate amount of surface friction to cause the needles to etch brown and in advance of the fillings.

The "white martensite" needles or areas seem to indicate zones along crystallographic planes which have lagged behind rather than preceded the interspaces in the rapidity of transformation. They probably contain a little untransformed gamma iron. The freshly transformed alpha iron may or may not be uniformly oriented. The evidence here is not complete.

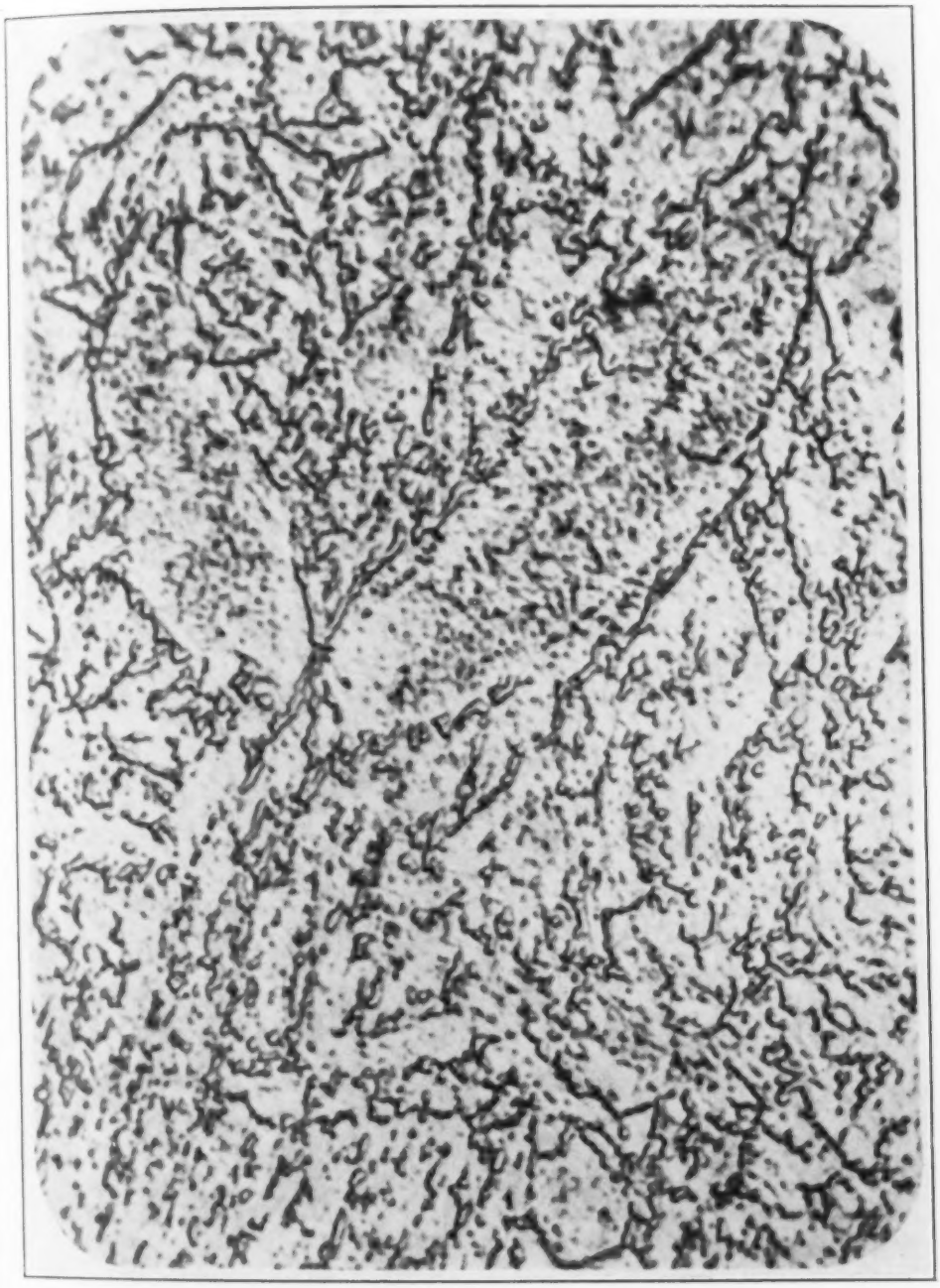

FIG. 13—SPECIMEN NO. 34—"AS QUENCHED AND TEMPERED AT 600 DEGREES CENT. (1112 DEGREES FAHR.)"

MAGNIFICATION × 3500

Rockwell Hardness C32

Tempering ten minutes at 600 degrees Cent. (1112 degrees Fahr.) has caused the hardness to drop from about C68 to C32. The structure shows the old needle and nodule outlines. The background or matrix is ferrite and the old "as quenched" pattern is fully marked in outline by very small carbides. The needle areas contain a great many very small carbide particles.

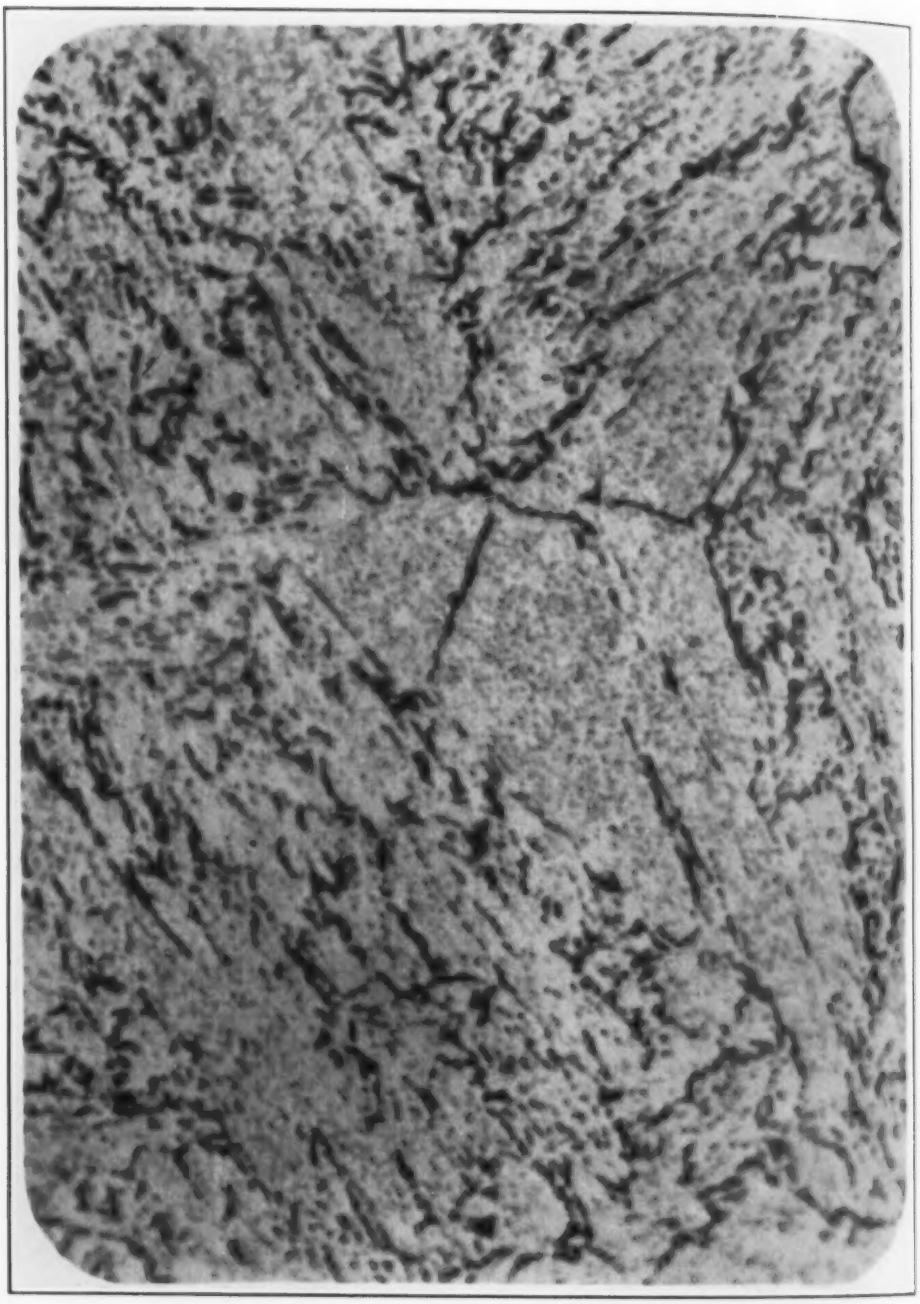

FIG. 14—SPECIMEN NO. 34—"AS QUENCHED AND TEMPERED AT 600 DEGREES CENT. (1112 DEGREES FAHR.)"
MAGNIFICATION × 3500
Rockwell Hardness C32

This is the same specimen shown in Fig. 13, except that for this illustration, it was etched with sodium picrate. This reagent stains iron carbide dark. Compare with Fig. 13. A specimen in the "as quenched" condition stains dark also, but the individual carbide particles are not resolved. The carbide particles are present in all specimens tempered at 100 degrees Cent. (212 degrees Fahr.) or higher but the particles apparently grow in size until, as the higher tempering temperatures are reached, they become visible. Individuals seem to coalesce, thereby increasing the size; decreasing the number and thus improving contrast between the field (ferrite) and the particles.

FIG. 15—SPECIMEN NO. 35—"AS QUENCHED AND TEMPERED AT 650 DEGREES CENT. (1202 DEGREES FAHR.)"

MAGNIFICATION × 3500

Rockwell Hardness C28

Tempered at 650 degrees Cent. (1202 degrees Fahr.) the carbide particles are a little larger than in the specimen tempered at 600 degrees Cent. (1112 degrees Fahr.). They are a little more clearly defined and the steel is a little softer.

In the writer's opinion the difference between martensitic needles and troostitic nodules does not lie in the ultimate constituents. Both seem to be composed of alpha iron and iron-carbide. It is the way in which the two structural forms have developed and the particle size of the carbide. In the martensitic needle a "mid-rib" is found, indicating the plane along which decomposition first took place. On each side of the mid-rib is a tapering zone. These zones are not as fully transformed as the mid-rib because the mid-rib etches out forming a trough (1). The inner crystalline orientation of the needle appears in all cases to be the same as the orientation of the original austenite. In troostite, however, we have very definite evidence that the larger nodules develop about a nucleus usually a void or an inclusion and form into a ball (10). If we section one of these nodules we find the nucleus at the center with radial grains radiating from it. A section of a troostitic nodule often looks like a wagon wheel in which the hub is the nucleus and the spokes are grain boundaries. In the case of troostite the freshly transformed alpha iron appears to have re-oriented itself without following in all details the old austenite crystalline symmetry.

A number of typical photographs have been selected to illustrate the sequence of events described in this paper. The titles have been so worded as to supply a complete description and, therefore, the illustrations are not referred to specifically in the text.

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DISCUSSION

Written Discussion: By Dr. Albert Sauveur, Harvard University, Cambridge, Mass.

I have read Mr. Lucas' paper with a great deal of interest. His high power photomicrographs come up to the high standard of excellence which he has taught us to expect from him, and the skill displayed in preventing any tempering of hardened steel during the polishing operation is impressive. While I agree with many of the author's views, I find myself not quite prepared to accept them in their entirety. I am glad that he focuses our attention sharply to the two constituents of the martensitic structure, namely the needles and the ground mass or matrix. By doing so, he shows the unreasonableness of regarding martensite as a single constituent. It is of primary importance that we should know the nature of the needles and of the surrounding matrix. Mr. Lucas expresses the belief that the ground mass marks an earlier step in the decomposition of austenite than the needles. I find it difficult to accept that conclusion. I also believe that it conflicts with his statement that the needles form along crystallographic planes of the original austenite grains, which, in my opinion, must be the mechanism of austenite decomposition. When the new alpha phase forms, it does locate at the crystallographic planes of the parent solid solution, resulting in an aggregate of the two phases, namely gamma and alpha, which constitutes the so called martensitic structure. At the instant of its formation the alpha phase, constituting the needles, may and probably does retain the carbon in supersaturated solid solution but owing to the slight solubility of carbon in alpha iron carbide is readily precipitated within the alpha phase converting it, I believe, into troostite.

I am well aware that the views I have just expressed seem to be opposed by some of the results described in the present paper. Nevertheless, they appear to me to be based on such firm ground that I cannot abandon them without further evidence opposing them.

Referring to the white needles so skillfully brought out by Mr. Lucas, I consider these to be the alpha phase first formed when austenite decomposes and in which the carbon may be in solution or more probably partly in solution and partly in extremely finely divided particles of the carbide. I do not think that the fact that the matrix, which I believe to be undecomposed austenite, etches more readily than the white needles should be taken as a conclusive evidence that instead of being undecomposed austenite it corresponds to a more advanced stage of austenitic decomposition than the needles.

DR. HARDER: In connection with Mr. Lucas' drawing experiments, I would like to ask what was the drawing time. From the results which he obtained, I assume that they were drawn over a rather long period of time.

I would like to ask further if examination was made of this steel with reference to inclusions. Some of the structures which are of the character of nodular troostite suggest to me either a lack of uniform carbon distribution in the austenite or the presence of some inclusions which may modify that formation.

Finally, I noticed Mr. Lucas uses the term "cleavage plane," which has had a more extensive use in minerals and means a brittle plane, whereas I doubt if this is a brittle plane but rather a plane of slippage. Perhaps this is not a case of cleaving or fracturing on this plane at all but a case of a slippage along a plane which disturbs a metastable system and therefore causes the transformation to take place along that line.

MR. AUSTIN: I would like to see whether Mr. Lucas can possibly complete the picture that I have of these transformations, particularly the formation of troostite. I have observed that it usually occurs in the grain boundaries and in this rosette appearance, and that the transformation seems to be exceedingly rapid, indicating some sort of a seating effect; that is, that you usually do not get the troostite, that is just a part of the structure in the troostitic condition, except as the specimen is quenched. If you try to reproduce that later by annealing, the reaction seems to be so rapid that it passes entirely through, that is, it passes directly from the martensitic over to the troostitic, the entire structure is troostitic, and not having the contrast, the nature of the product is not so evident. I was wondering whether he could picture some chemical or physical change which involves possibly a seating effect which would be very rapid and which would account also for the apparent difference in chemical properties between martensite and troostite which result in the very large contrast in etching.

W. T. GRIFFITHS: I should like to ask Mr. Lucas and the other gentlemen who work on this decomposition of austenite into martensite whether we can today say any more definitely what we mean when we talk of "martensite". Are we to take it that on the transformation of the gamma solid solution one immediately obtains a separation of the newly formed alpha iron and the carbide?

Just before the austenite and martensite transformation takes place we apparently have a uniform solid solution. If the rate of cooling is rapid or the temperature of the transformation is low—it may approach room temperatures—it is possible that the transformation of the gamma to alpha iron may progress outward from its point of initiation at a more rapid rate than the separated carbon atoms can diffuse together to give the number necessary to form the cementite lattice. (If you consider the question you will find that in a gamma iron solid solution containing 0.30 per cent carbon, the carbon atoms will have to travel quite a distance in order to collect in the groups of four necessary for what we now think is the lattice of cementite.) In this case we presumably can have the greater part of the carbon trapped in the alpha iron lattice as separate atoms and obtain what has

been termed an "enforced solid solution of carbon in alpha iron".

On the other hand, if the rate of cooling below 900 degrees Fahr. is low or the change point is high, say 750 to 650 degrees Fahr., it is possible that all the carbon will have time to "get away" from the alpha iron and be present after the change only in particles (possibly ultramicroscopic) of cementite.

Thus, we may have any one of a series of structures representing all the states from almost complete "solution" of the carbon in alpha iron to entirely discrete particles of alpha iron and carbide and the question arises as to what we include under the term "martensite". If we say that this is the product of the Ar″ point, then we must include structures which have quite a low hardness (below 350 Brinell) while if we take hardness as criterion, it is necessary to stipulate the lower limit of hardness that we include and possibly exclude some structures produced at the Ar″ point.

I first pointed out these effects of rate of cooling and position of the Ar″ point some five years ago* and the work which Mr. Lucas and others are doing appears to agree quite well with the ideas then outlined. There are still, however, a number of investigators who appear to think that the term "martensite" applies to something quite definite and I should therefore personally much appreciate Mr. Lucas' views on the present meaning of the term.

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*"The Change Points in Some Nickel Chromium Steels." *Journal* of the Iron and Steel Institute, 1923, No. II, p. 133.
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CONSTITUTION OF ALUMINUM-COPPER ALLOYS

By E. H. Dix, Jr.,* and H. H. Richardson†

THE aluminum rich alloys of the aluminum-copper system are of great commercial importance in both wrought and cast forms. The wrought alloys generally do not contain over 5 per cent copper, although the cast alloys may contain as much as 12 to 15 per cent copper. With further increase in copper content the brittleness of the alloys is too great to permit more than a few special commercial applications. Both the wrought and cast alloys are subject to improvement in strength and hardness by heat treatment.

Because of the commercial importance of the aluminum-copper alloys the constitution of this system has been the subject of a number of independent researches. At the aluminum end of the series the compound $CuAl_2$, containing approximately 54 per cent copper, forms a eutectiferous series with aluminum, in which the eutectic alloy contains 33 per cent copper and melts at 548 degrees Cent. At the eutectic temperature 5.65 per cent copper is soluble in solid aluminum, and this amount decreases to less than 0.5 per cent at room temperature. The susceptibility of the aluminum-copper alloys to improvement in strength by heat treatment depends on this decrease in solubility.

The diagram of Fig. 1 is according to the most recent work of Stockdale,[7] but modified in the composition range shown in the insert to agree with the later investigation of Dix and Richardson.[9] The diagram of Stockdale differs, in the range shown, from the earlier one of Carpenter and Edwards[1] only in that the liquidus is more nearly horizontal from about 49 per cent copper to the compound $CuAl_2$ and that this compound is shown to be incapable of holding any aluminum in solid solution. However, the experimental evidence on this latter point appears to be inconclusive.

There is a decided lack of agreement between the results obtained in four comparatively recent investigations of the solubility of copper in solid aluminum. The discrepancies are probably due to impurities in the aluminum used and to the long time required to obtain true equilibrium.

Merica[3] and his associates discovered that the solubility of copper in aluminum decreased with decrease in temperature and called attention to the connection between this fact and the susceptibility of the alloys of the duralumin type to improvement in strength and hardness by heat treatment.

The solubility data shown in the following tabulation and the insert of Fig. 1 were arrived at by microscopic examination of alloys of extremely high purity, which had been annealed for long periods of time:

*Metallurgist, Research Bureau, Aluminum Company of America, New Kensington, Pa.

†Assistant Metallurgist, Research Bureau, Aluminum Company of America, New Kensington, Pa.

Prepared for the Nonferrous Data Sheet Committee of the Institute of Metals Division of the A. I. M. E. and the Recommended Practice Committee of the A. S. S. T.

SATURATION LIMIT OF COPPER IN SOLID ALUMINUM ACCORDING TO DIX AND RICHARDSON

Temperature, °C.	200	300	350	400	450	500	548
Per cent Copper	0.50	0.70	0.95	1.45	2.65	4.15	5.65

These results are in fair agreement at the eutectic temperature with the result obtained by Rosenhain[4] at the National Physical Laboratory and at 300 degrees Cent. with that of Merica[3] at the U. S. Bureau of

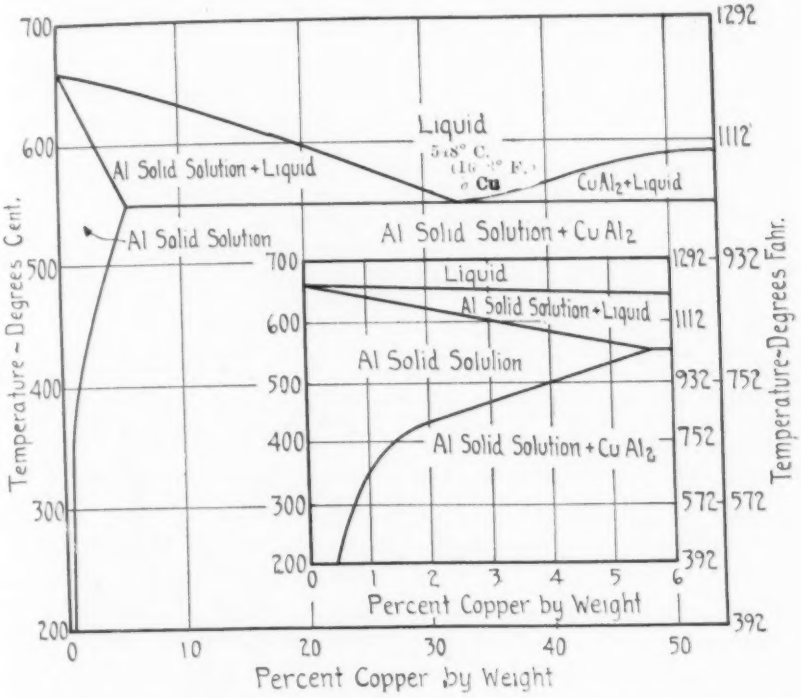

Fig. 1—Aluminum-Copper Equilibrium Diagram (Stockdale, Dix and Richardson).

Standards. They also agree with the results obtained by Ohtani and Hemmi,[5] who used electrical resistivity measurements for a limited temperature range of 420 to 520 degrees Cent. The solubility at 200 degrees Cent. was obtained on chill cast specimens annealed at that temperature for two weeks subsequent to a homogenizing treatment of 11 days at 540 degrees Cent.

The compound $CuAl_2$, when it occurs in the light aluminum alloys, polishes slightly in relief and has a marked tendency to tarnishing. However, if carefully polished it is clear and almost colorless, with a slightly pink tinge. Its most striking characteristic is the way in which it lights up in passing out of focus. A light etch with 0.5 per cent hydrofluoric acid leaves this constituent clear with a well defined boundary. It is colored brown or black by immersion for 40 seconds in 25 per cent nitric acid at 70 degrees Cent., followed by quenching in cold water.

The solid solution of copper in aluminum has been shown by X-ray analysis[6,8] to have a face centered cubic lattice similar to that of pure aluminum. Solution of copper is effected by simple substitution without a measurable change in the size of the lattice. The structure of the compound $CuAl_2$ has been studied by two investigators,[6,8] but their results are in disagreement.

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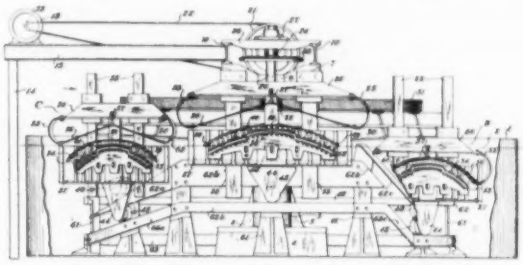
Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,682,734, Sept. 4, 1928, Spring Forming and Tempering Machine, John F. Beans and Bernard L. Le Roy, of Massillon, Ohio.

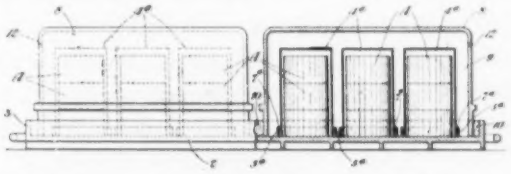
This patent describes a spring forming and tempering machine consisting of a turret platform carrying a plurality of spring clamping heads 54 adapted to receive a hot spring blank and hold it in position by means of the fingers 55. The clamping heads are movable along an inclined track 63a,



63b and 63c to effect the opening and closing operation and to immerse and pass the heated blanks through an oil quenching bath. The apparatus is adapted for continuous operation and is semi-automatic.

1,682,801, Sept. 4, 1928, Apparatus for Annealing, James E. Robertshaw, of Bedford, Ohio, Assignor to the American Steel and Wire Company of New Jersey, a corporation of New Jersey.

This patent describes an annealing apparatus in which the material undergoing annealing is protected from oxygen in the annealing box to prevent discoloration of the same. The apparatus comprises an annealing box 8



resting upon a suitable base 2 with a sand seal 10 around the edges thereof, the annealing box being provided with openings 12 for the flow of non-oxidizing gas therethrough. The coils of sheet material A are placed upon the bottom of the annealing box and are provided with separate covers 4a closed by sand seal 7a to protect the material from any oxygen in the gases within the annealing box.

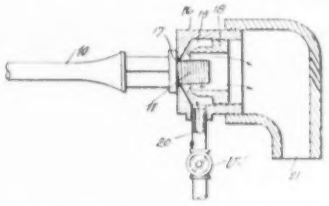
1,689,630, Oct. 30, 1928, Heat Treating Magnesium Alloys, Zay Jeffries and Robert S. Archer, of Cleveland, Ohio, Assignors to American Magnesium Corporation, of Niagara Falls, New York, a corporation of New York.

This patent describes the heat treatment of a magnesium base alloy, such

as a casting containing from 3 to 15 per cent aluminum, up to 5 per cent of zinc, cadmium up to 10 per cent, copper up to 2 per cent, manganese up to 2 per cent, with the remainder magnesium, which is subjected to heat treatment at a temperature slightly below the melting point of the most fusible constituent for an extended period of time and up to 70 hours. This heat treatment increases the plasticity of the metal, improving the drawing, rolling and forging properties of the alloy. It is preferable to work the metal while it is hot. It is desirable to enclose the metal in an iron container and maintain an inert atmosphere to prevent burning of the metal.

1,688,705, Oct. 23, 1928, Method of Heat Treating Sucker Rods, Jesse L. Gray, of Los Angeles, California, Assignor, by Mesne Assignments, to L. P. Burgess, D. Daniels, and J. O. Clutter, Trustees.

This patent describes a method and apparatus for heat treating sucker rods for deep well pumps, which comprises heating the threaded portion 11 to the transformation point, rapidly quenching the threaded portion by directing



a fluid from the pipe V around the edges thereof, promptly removing the quenched portion from the quenching medium to allow the retained heat of the unquenched portion to flow into the quenched portion to draw the temper of the quenched portion and to convert the heat-treated section to a troostitic or sorbitic structure which has a high, shock resisting strength and is well suited for pump rod purposes.

1,692,842, Nov. 27, 1928, Method of Manufacturing Black-Heart Malleable Cast Iron From White Cast Iron, Tario Kikuta, of Tobata City, Fukuoka Ken, Japan, Assignor to Tobata Imono Kabushiki Kaisha, of Tobata City, Fukuoka Ken, Japan, a corporation of Japan.

This patent describes a method of manufacturing black heart malleable castings from white cast iron without the use of a packing material, which comprises first maintaining the white cast iron at a temperature between 850 and 950 degrees Cent. for 15 to 60 hours, then cooling the iron to a temperature between 730 and 650 degrees Cent., then maintaining the iron at the latter temperature for 20 to 50 hours, and then removing and cooling the iron rapidly. The essential point is to cool the product rapidly after carrying out the complete graphitization of the combined carbon contained in the white cast iron in two stages.

1,686,696, Heating Furnace. Josef Hirschmann, Baltimore, Md., assignor to The Eastern Rolling Mill Company.

In this heating furnace material such as sheet metal is conveyed through the furnace on a number of parallel supporting and conveying elements, supporting wheels being connected to these elements. These

wheels are supported on rails which are also arranged in different independently movable groups, the groups of rails being alternately raised and lowered, means being provided for imparting reciprocating motion to these rails.

1,695,044, **Dec. 11, 1928, Process for Increasing the Electrical Conductivity and the Flexibility of Metals or Alloys, Karl Hallmann, of Munich, Germany.**

This patent describes the process for improving the electrical conductivity and flexibility of metals or alloys which have been subjected to heat treatment. The process comprises first heating the alloy to an annealing temperature, then cooling, then subjecting the alloy in a mechanical working, bringing about a reduction in diameter at low temperature, that is cold drawing, and finally heating an aluminum wire alloy to a temperature of 160 to 200° centigrade and then permitting cooling. Ordinarily, the heat treating step reduces the electrical conductivity and the flexibility of the metal and the subsequent reduction in diameter and subsequent heating substantially restores the electrical conductivity and flexibility to that of the original alloy before heat treatment. It is sometimes preferable to allow a period of two or three days for aging between the annealing operation and the reduction in diameter.

1,697,130, **Jan. 1, 1929, Nickel Manganese Steel Alloy and Method of Treating the Same, Charles McKnight, Jr., of Montclair, N. J., and Thomas H. Wickenden, of Roselle, N. J., and Paul D. Merica, of New York, N. Y., Assignors to the International Nickel Co., of New York, N. Y., a corporation of New Jersey.**

This patent describes a nickel manganese steel alloy containing approximately 0.10 to 0.60 per cent of carbon, 0.70 to 2 per cent manganese, 0.50 to 3.50 per cent nickel, and the remainder iron. This alloy, when subjected to a mild heat treatment, such as by annealing, double annealing, quenching in air and treating, is particularly desired for forgings and structural shapes. It shows the tensile strength of 85,000 to 110,000 and the yield point of 55,000 to 80,000.

1,695,922, **Dec. 18, 1928, Process of Heat Treating Steel, Le Baron W. Kinney, of Cleveland, and George H. Bierman, of East Cleveland, Ohio, Assignors to the White Motor Company, of Cleveland, Ohio, a corporation of Ohio.**

This patent describes a composition for preventing decarburization of steel such as gears undergoing heat treatment in an electric furnace, as it has been found that gears which are heat treated in an electric furnace are found relatively softer on their surfaces than similar articles heat treated in gas fired or oil burning furnaces. The material used to prevent the decarburization of such articles in an electric furnace consists of a compound of one part kieselguhr, two parts borax, and four parts of water.

THE ENGINEERING INDEX

Registered United States, Great Britain and Canada

Arrangements have been made with The American Society of Mechanical Engineers whereby the American Society for Steel Treating will be furnished each week with a specially prepared section of The Engineering Index Service. It is to include items descriptive of articles appearing in the current issues of the world's engineering and scientific press of particular interest to members of the American Society for Steel Treating. These items will be selected from the Weekly Card Index Service of the Index published by the A. S. M. E.

In the preparation of the Index by the staff of the A. S. M. E. some 1,700 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. will be supplied with a selective index to those articles which deal particularly with steel treating and related subjects.

Photostatic copies (white printing on a black background) of any of the articles listed may be secured through the A. S. S. T. The price of each print, up to 11 by 14 inches in size, is 25 cents. Remittances should accompany orders. A separate print is required for each page of the larger periodicals, but whenever possible two pages will be photographed together on the same print. When ordering prints, identify the article by quoting from the Index item: (1) Title of article; (2) name of periodical in which it appeared; (3) volume, number, and date of publication of periodical; and (4) page numbers.

AIRPLANES

MANUFACTURE—ALUMINUM RIVETS. Aluminum Alloy Rivets in Aircraft Construction, W. Nelson. *Airway Age*, vol. 9, no. 12, Dec. 1928, pp. 44-47, 5 figs.

Rivets of aluminum alloys can be used with great success if proper precautions are observed; identification of rivets, after they are manufactured and before they are driven, is extremely important; in structures made of relatively pure aluminum, aluminum rivets should be used; types of heads and points; design factors; machine tools for riveting; driving of rivets.

ALLOY STEELS

DURABILITY. Permanence. *Metallurgist (Supp. to Engineer, Lond.)*, Oct. 26, 1928, pp. 145-146.

It is claimed that some civil engineers still hesitate to adopt such materials as heat-treated alloy steels for bridge construction on ground that they are not satisfied as to its permanence; they raise question whether properties imparted to alloy steel by heat treatment may not undergo gradual change in course of time; author examines possible doubts of these engineers and demonstrates their fallacy.

TEMPERATURE EFFECT. Effect of Alloying Elements Upon the Stability of Steel at Elevated Temperatures, A. E. White and C. L. Clark. *Am. Soc. Mech. Engrs.—Advance Paper*, no. 35, for mtg. Dec. 3-7, 1928, 21 pp., 54 figs.

Short-time tensile tests were conducted on large number of alloy steels, chemical composition of which is given; advances theory or hypothesis accounting for stability of various types of steels at elevated temperatures, and gives specific data on various types of steels when in annealed or normalized state, and effect of heat treatments.

ALLOY STEEL CASTINGS

Alloy Cast Steel, D. Hanson. *Foundry Trade Jl. (Lond.)*, vol. 39, nos. 637 and 638, Nov. 1 and 8, 1928, pp. 319-321 and 337-339 and (discussion) 339-340, 17 figs.

Effect of nickel on constituents of cast iron; comparison of effects of nickel and silicon; scientific use of alloy additions; effect of nickel on properties such as iron chill and hard spots, grain, hardness, strength and on machineability. Nov. 8: Nickel and chromium in cast iron; effect of nickel in presence of phosphorus.

HEAT TREATMENT. Tentative Recommended Practice for the Heat Treatment of Alloy Steel Castings. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 6, Dec. 1928, pp. 935-939.

Recommended practice applies generally to commercial alloy castings for ordinary construction purposes and not for special use; chemical compositions of steel considered are given.

ALUMINUM

CASE HARDENING. Special Case Hardening of Aluminum and Duralumin after Double Electroplating (Sur quelques cémentations spéciales de l'aluminium et du duralumin aprés double dèpat électrolytique), J. Cournot and E. Perot. *Métallurgie (Paris)*, vol. 60, no. 43, Oct. 25, 1928, pp. 25-26.

Description of effect of plating on aluminum or duralumin with two different metals, first copper, then nickel or chromium, cobalt or cadmium; micrographic and physical characteristics. Paper presented before French Academy of Science, May 23, 1927.

Those members who are making a practice of clipping items for filing in their own filing system may obtain extra copies of the Engineering Index pages gratis by addressing their request to the society headquarters, whereby their names will be placed on a mailing list to receive extra copies regularly.

RECRYSTALLIZATION. Recrystallization of Aluminum (Rekristallisationserscheinungen bei Aluminium), A. E. Van Arkel and M. G. Van Bruggen. *Zeit. fuer Physik (Berlin)*, vol. 51, nos. 7 and 8, Oct. 27, 1928, pp. 520-533, 9 figs.

Second report of theoretical and experimental studies, at laboratory of N. V. Philips incandescent lamp plant on recrystallization of commercial and chemically pure aluminum subjected to great distortion stresses.

RECRYSTALLIZATION. Recrystallization of Single Crystals of Aluminum, (Rekristallisation von Aluminium-Einkristallen), W. G. Burgers and J. C. M. Basart. *Zeit. fuer Physik (Berlin)*, vol. 51, nos. 7 and 8, Oct. 27, 1928, pp. 545-556, 8 figs.

Results of laboratory study of orientation of crystals forming after large single crystals have been subjected to comparatively low distortion stresses.

AUTOMOBILES, BODIES

STEEL. Sheet Steel for Automobile Bodies. *Heat Treating and Forging*, vol. 14, no. 11, Nov. 1928, pp. 1286-1289, 11 figs.

Advantages of continuous box annealing of sheets are outlined and resulting physical properties shown; detailed description of furnaces and their operation.

BEARING METALS

Economies Effected by the Use of New Bearing Metal, N. T. Shaw. *West. Machy. World*, vol. 19, no. 11, Nov. 1928, pp. 479-480, 6 figs.

Bearing metal which meets requirements satisfactorily is being made by International Metal Sales Co. of San Francisco; this Shaw metal is alloy of copper and lead, containing no other metal or abrasive; it can be made in any proportion of lead and copper to suit operating conditions, and can be remelted and recast without losing its inherent qualities.

White Metal Alloys for Bearings, their Treatment and Microstructure, O. G. Styrie. *Eng. Progress (Berlin)*, vol. 9, no. 11, Nov. 1928, pp. 318-320, 5 figs.

White metal is only for non-adjustable bearings; researches of Bauer and Heyn on bearing alloys, especially ternary tin-antimony-lead system showed new ways to improve this alloy by adding copper; this quaternary alloy is basis for bearing-metal standards established by German Standards Committee; low percentage tin alloy, known as "Thermit"-Brand anti-friction metal, consists chiefly of lead hardened by adding constituents with high melting point, such as nickel.

BRONZE. Wear and Mechanical Properties of Railroad Bearing Bronzes at Different Temperatures, H. J. French, S. J. Rosenberg, W. L. Harbaugh and H. C. Cross. *U. S. Bur. Standards—Jl. of Research*, vol. 1, no. 3, Sept. 1928, pp. 343-421, 62 figs. partly on supp. plates.

Bronzes were tested under rolling and sliding friction without lubrication at atmospheric and elevated temperatures; under tension impact, and pounding at temperatures from 7 to 600 deg. fahr.; detailed description is given of all apparatus used in tests.

BLAST FURNACES

Burgers System of Blast Furnaces with Watercooled Metallic Stack Without Brick Lining (Les hauts-fourneaux du système Burgers à cuve métallique arrosée sans machonnerie intérieure), E. de Loisy. *Revue de Métallurgie (Paris)*, vol. 25, no. 10, Oct. 1928, pp. 557-562, 10 figs.

Description of a Burgers system blast furnace, its operation and results obtained.

BLAST FURNACE PRACTICE

COLD BLAST. Some Notes on the Loss of Pressure and Temperature in Cold-Blast Lines, J. S. Fulton. *Engrs. Soc. West. Pa.—Proc.*, vol. 44, no. 5, June 1928, pp. 159-167 and (discussion) 167-172, 3 figs.

Possibility of improvements in method of handling wind after it has left blowing-engine house; temperatures in cold-blast lines tabulated in table.

BRASS FOUNDRY PRACTICE

Tests Show Value of Deoxidizing Agents, C. Vickers. *Foundry*, vol. 56, no. 22, Nov. 15, 1928, pp. 931-933 and 946.

Effect of aluminum as deoxidizer on copper; precautions to be taken to secure clean sound sand castings of aluminum bronze; conductivity of silico-calcium deoxidized copper; producing boron-copper castings; results of tests with magnesium in copper; copper should be best electrolytic obtainable; production of calcium copper; boron suboxide as deoxidizer, and high conductivity of copper treated with it.

The Fundamentals of Brass Foundry Practice, R. R. Clarke. *Metal Industry (N. Y.)*, vol. 26, no. 12, Dec. 1928, p. 517, 1 fig.

Advantages of bottom pouring include placid delivery, its skimming function, its lesser tendencies to entrap air, gases and dross in casting metal and greater compactness of its delivered metal.

COST ACCOUNTING. Brass Founders' Accounts, W. H. Withey. *Metal Industry (Lond.)*, vol. 33, no. 20, Nov. 16, 1928, pp. 461-462.

Analysis of time worked; mode of checking entries; system of labeling stores; methods of determining depreciation.

BRICK

SILICA. A Comparison of the Properties and Industrial Durability of Lime-Bonded and Clay-Bonded Silica Bricks, W. J. Rees and W. Hugill. *Engineering (Lond.)*, vol. 126, no. 3278, Nov. 9, 1928, p. 602.

Digest of report of investigation which appeared as Bulletin No. 15 of British Refractories Research Assn. Brief abstract of paper read before Ceramic Soc.

BRIQUETTING

IRON BORINGS. Briquetting Cast Iron Borings for Remelting in Cupola. *Sibley Jl. of Eng.*, vol. 42, no. 8, Nov. 1928, pp. 289 and 308, 2 figs.

In Dodge Bros. foundry, cast-iron borings are now being remelted; made possible by compressing loose, powder-like cast-iron chips under intense hydraulic pressure into briquettes; formed under total pressure of from 600,000 to 800,000 lbs.

BRONZE FOUNDRY PRACTICE

Close Control and Reclamation System, E. Bremer. *Foundry*, vol. 56, no. 22, Nov. 15, 1928, pp. 912-916, 8 figs.

Methods of casting bearing bronzes in plant of Lumen Bearing Co., Buffalo, N. Y., are described; 140 standard and special alloys including aluminum bronze, phosphor bronze, and manganese bronze, are made; alloys melted in oil-fired furnaces of crucible and non-crucible type, and in electric furnace; core making; cleaning castings; pattern storage; examination of alloy structure and other testing; reclamation plant.

CASE HARDENING

CARBURIZING. On the Relation Between the Quantity and the Depth of Carburization, G. Takahashi. *Tohoku Imperial Univ.— Sci. Reports (Tokyo)*, vol. 17, no. 6, Sept. 1928, pp. 1135-1156, 15 figs.

Cementation was carried out for various intervals of time and at different temperatures, using several kinds of carburizing agents, and quantity of carbon diffused into iron determined by weight increase, and thickness of cemented zone by microscope.

CARBURIZING. Modernized Equipment for Carburizing, F. W. Manker. *Heat Treating and Forging*, vol. 14, no. 11, Nov. 1928, pp. 1326-1327, 1 fig.

Description of efficient devices for handling and heating at plant of Willys-Overland Co.; carburizing department is located in separate building; 5 principal furnaces located in single row, longitudinal axis of each paralleling others with quenches in front; here camshafts, steering worm gears, and small miscellaneous parts are carburized after having been machined; arrangements for treating camshafts; control of heating cycle.

NITRATION. A new Method of Nitrogen Case Hardening, G. F. Bason. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 6, Dec. 1928, pp. 932-934.

Investigation of hardening of collector rings on electrical machinery; it is believed that this hardening may be due to ring being bombarded with nitrogen ions, thereby nitrogenizing surface of steel; it is suggested that this process be more or less closely imitated as possible means of evolving practical method of nitriding superior to present ones.

CASTINGS

CLEANING. Cleaning Room Aids Production of Quality Castings, F. G. Steinebach. *Foundry*, vol. 56, no. 22, Nov. 15, 1928, pp. 943-946, 6 figs.

Equipment for handling materials in foundry cleaning rooms; applications of chain block, pneumatic and electric hoists; types of monorail equipment.

CLEANING—CORE REMOVAL. Removes Cores Hydraulically, J. Prendergast. *Foundry*, vol. 56, no. 22, Nov. 15, 1928, pp. 922-925, 7 figs.

Development of hydraulic method for cleaning castings is outlined; methods of cleaning cores at Claremont, N. H., and Michigan City, Ind., plants of Sullivan Machinery Co., are described; accidents in cleaning department reduced by hydraulic method; fewer men required; cost of installation; expenses of operation and estimated yearly savings shown.

CAST IRON

ALLOY. Cast Iron with Nickel and Chromium Alloys (Ueber nickel und chromlegiertes Gusseisen), E. Piwowarsky. *Giesserei (Duesseldorf)*, vol. 15, no. 43, Oct. 26, 1928, pp. 1073-1078, 8 figs.

Discussion of literature covering experimental results on influence of nickel or chromium, or combination of both on properties of cast iron. Bibliography.

ANALYSIS. A Study of the Hydrogen-Antimony-Tin Method for the Determination of Oxygen in Cast Irons, B. Kjerrman and L. Jordan. *U. S. Bur. of Standards—Jl. of Research*, vol. 1, no. 5, Nov. 1928, pp. 701-720, 2 figs.

Important that lump samples rather than milled samples be used in either vacuum fusion or hydrogen-antimony-tin reduction methods in order to avoid erroneous results for oxygen; for application to cast iron containing oxygen within range of samples used, from 0.01 to 0.04 per cent, former method is to be preferred on basis of its greater precision; complexity of blank corrections necessary in application of hydrogen reduction method to high-carbon iron alloys is pointed out and discussed.

GRAPHITIZATION. Some Theories of Graphitization, H. A. Schwartz. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 636, Oct. 25, 1928, pp. 297-298.

According to American nomenclature, formation of free carbon during freezing is called primary graphitization and that during subsequent heat treatment secondary graphitization; author considers latter conditions principally; physico-chemical aspect; how carbon migrates; effect of elements on graphitization; sulphides inhibit graphite migration; influence of manganese. Exchange paper of Am. Foundrymen Assn., presented before Assn. Technique de Fonderie. See also Am. Metal Market, vol. 35, no. 216, Nov. 10, 1928, pp. 1-5 and 29, 2 figs.

GRAPHITE FLAKES. On the Photomicrography and Metallography of Graphite Flakes, A. L. Norbury and L. W. Bolton. *Brit. Cast Iron Research Assn.—Bul. (Birmingham)*, no. 22, Oct. 1928, pp. 52-54, 10 figs. on supp. sheet.

Photomicrographs of graphite flakes may represent flakes as larger than their true size if methods of polishing and focusing are incorrect; burnish polishing, on other hand, may make some flakes too small and actually cover over others; presence of "ferrite networks" in photomicrographs of graphite flakes is not confirmed, and is shown to be due to focusing on cavities containing remnants of graphite flakes.

GROWTH. Influence of Carbon, Manganese and Silicon on Growth of Cast Iron (Der Einfluss von Kohlenstoff, Mangan und Silizium auf das Wachsen des Gusseisens), I. Bauer and K. Sipp. *Giesserei (Duesseldorf)*, vol. 15, no. 42, Oct. 19, 1928, pp. 1047-1060, 60 figs.

Investigation of structure; results are shown in tabular form and in photomicrographs.

OXYACETYLENE WELDING. Choice of Cast Iron Welding Methods, P. L. Roberts.

Welding Engr., vol. 13, no. 11, Nov. 1928, pp. 33-34, 2 figs.

Size and shape of parts, preheating facilities, importance of avoiding warping, and other factors influence choice of procedure and materials; application of principles is illustrated by two types of cast-iron welding jobs.

PROPERTIES. Methods for Evaluating Properties of Cast Iron, J. E. Hurst. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 638, Nov. 8, 1928, p. 343.

Discussion of paper published in Oct. 18, 1928, issue of journal; formula is referred to which took account of effect of manganese and phosphorus also, on cast iron; suggests use of sliding panel to correct differences in thickness of iron.

STANDARDS—GERMANY. Standardization of Iron Castings. *Brit. Cast Iron Research Assn.—Bul. (Lond.)*, no. 22, Oct. 1928, pp. 62-64.

German Standardization Committee has issued standardization sheet in connection with cast iron in which various types of castings made are classified into nine divisions and where mechanical tests are necessary these are given; in addition general stipulations regarding all iron castings are given.

STRUCTURE. Constituents and Texture of Cast Iron (Constituants et texture des fontes), J. Seigle. *Revue de l' Industrie Minéral (Paris)*, no. 189, Nov. 1, 1928, pp. 427-442, 12 figs.

Discussion of pearlitic cast iron and graphical representation of its constituents; chilled iron castings, steel castings, influence of constituents on texture and properties; calculation of exact percentage of constituents.

CHROMIUM PLATING

Present Status of Chromium Plating, From the Industrial Point of View (Estado actual de la electrolisis del cromo desde el punto de vista industrial), J. L. Herran. *Anales de la Asociacion de Ingenieros (Madrid)*, vol. 7, no. 9, Sept. 1928, pp. 481-486.

Brief historical review of chromium; electrolytic deposition of chromium and chrome nickel; technical practice.

CHROMIUM STEEL

ANTI-CORROSIVE. A New Development in Corrosion Resisting Steel, F. R. Palmer. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 6, Dec. 1928, pp. 877-888 and (discussion) 888-892 and 950, 7 figs.

Paper points out satisfactory means for improving machinability and grinding properties of high-chromium corrosion-resisting steels; effect of phosphorus and sulphur on these steels is briefly discussed, and use of zirconium sulphide is considered in detail; free-machining corrosion-resisting steel is described and its properties enumerated.

TESTING. Chrome and Cobalt Steels (Sur les aciers au chrome et au cobalt), F. M. Ostroga. *Metallurgie (Paris)*, vol. 60, no. 43, Oct. 25, 1928, pp. 26-27.

Author presents results of experiments on steels employed in exhaust valves of certain engines relative to transformation points and singular points on annealing curves; micrographic aspects.

CHROMIUM-SILICON STEEL

QUENCHING. Effect of Quenching and Tempering on the Hardness and Impact Resistance of a High Chromium-Silicon Steel, F. T. Sisco. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 6, Dec. 1928, pp. 859-865, 6 figs.

Result of investigation on quenching and tempering temperatures on alloy steel containing 1.2 per cent carbon, 1.2 per cent silicon, and 18.0 per cent chromium; best quenching temperature was found to be 1800 to 1850 deg. fahr.; steel retains its hardness at all temperatures below 1000 deg. fahr.; Izod impact values are low and are but little affected by varying tempering temperatures.

COPPER ALLOYS

X-RAY ANALYSIS. Spectography By X-Rays of Copper and Some Brasses (Spectrographie, par les rayons X, du cuivre et de quelques laitons), J. Loiseau. *Revue de Metallurgie (Paris)*, vol. 25, no. 10, Oct. 1928, pp. 572-584, 60 figs.

Series of experiments on X-ray spectra of copper alloys; description of methods employed and results obtained on various mixtures.

COPPER ALLOY CASTINGS

Some Notes on Non-Ferrous Casting Alloys, W. Lambert. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 638, Nov. 8, 1928, pp. 345 and (discussion) 346.

Author confines remarks to copper-aluminum bronzes and copper-tin group of alloys, latter group including various types of red brass, gunmetal, and phosphorus-bronze alloys; admiralty gunmetal best for gunmetal castings; general foundry procedure to secure sound castings in alloys of gunmetal and phosphor-bronze type fully expounded.

COPPER INDUSTRY

Copper Industry's Progress Since the War, W. G. Schneider. *Iron Age*, vol. 122, no. 22, Nov. 29, 1928, pp. 1374-1375, 2 figs.

Discussion of past, present and future of copper industry; new consumption record this year and condition now better than ever; world production must be increased; African copper not serious menace; new record this year in American consumption; higher prices will not affect use. Paper presented before Am. Inst. Min. and Met. Engrs.

CORE BINDERS

RUBBER. Rubber Binders for Foundry Cores. *Metal Industry (N. Y.)*, vol. 26, no. 12, Dec. 1928, pp. 511-512.

By use of rubber, balata, or thermoprene type of core binders it is possible to make, without any baking, cores of strengths varying from perhaps double that of ordinary green-sand core to that comparable to strength met in baked oil-sand cores; trial of rubber type of binders is recommended for castings in which present core binders show high cost for removal of cores; mixing plain rubber cement and Vulcalock cement. Abstract of Bur. of Standards—Letter Cir., no. 252.

CRYSTALS

ANALYSIS. Arrangement of Crystallites in Multiple Crystals (Textures) [Anordnung der Kristallite in Vielkristallen (Texturen)], E. Schmid. *Zeit. fuer Metallkunde (Berlin)*, vol. 20, no. 10, Oct. 1928, pp. 370-377, 26 figs.

Notes on anisotropy of crystals; methods of determining textures and results of research; growth, deformation, and recrystallization textures; significance of texture investigation for production of engineering materials of definite prescribed properties.

Crystallographic Principles of Crystal-Structure Analysis (Ueber die Kristallographischen Grundlagen der Kristallstruktur-Analyse), H. Mark. *Zeit. fuer Metallkunde (Berlin)*, vol. 20, no. 10, Oct. 1928, pp. 342-346, 7 figs.

Review of principles, processes, and results of X-ray analysis of crystals; notes on crystallographic system.

CUTTING TOOLS

ALLOYS. Cutting Alloys Affect Tool Design, E. F. DuBrul. *Iron Trade Rev.*, vol. 83, no. 23, Dec. 6, 1928, pp. 1442 and 1444.

Description of two new alloys for cutting tools, developed by Krupp Steel Works and General Electric Co., precedes discussion of three bulletins issued by National Machine Tool Builders Association dealing with effect of introduction of new cutting alloys; research program suggested; future market for machine tools; warning as to what might happen if industry does not meet situation now facing it.

DIE CASTING

Die Casting, A. H. Mundey. *Metal Industry (Lond.)*, vol. 33, no. 20, Nov. 16, 1928, pp. 467-468 and (discussion) 468-469.

Die casting described as method of producing castings in highly finished condition, accurate as to dimensions, with holes and inserts as required and screwed parts complete, by pouring or by forcing under pressures molten metal into well-finished permanent molds, or dies; consideration of equipment, operation and applications of die castings; magnesium and its alloys. In discussion silicon and manganese in die castings are referred to; nature of cores and molds. Brief abstract of paper presented before Instn. Eng. Inspection.

DIES, FORGING

Punches and Dies for the Bulldozer. *Am. Mach.*, vol. 69, no. 23, Dec. 6, 1928, p. 887, 5 figs.

Punches and dies for bulldozer are illustrated in five halftones from Canadian National Railways, each accompanied by brief description.

HEAT TREATMENT. Heat Treatment of Die Blocks, J. W. Urquhart. *Heat Treating and Forging*, vol. 14, no. 8, Aug. 1928, pp. 852-855 and 862.

Comparison of methods employed in England with those standard in United States; carburized plain and nickel-steel die block; chromium-steel die tools difficult to machine; shock-resisting nickel steels; author points out that presence of nickel in chromium steels serves to retard grain growth during prolonged heating at high hardening temperatures. See article in Metallurgist (Supp. to Engineer, Lond.), Oct. 26, 1928, pp. 153-154, referring to Am. Soc. Steel Treating report and to above article.

DURALUMIN

CASE HARDENING. Special Case Hardening of Aluminum and Duralumin after Double Electroplating (Sur quelques cémentations spéciales de l'aluminium et du duralumin aprés double dépot électrolytique), J. Cournot and E. Perot. *Métallurgie (Paris)*, vol. 60, no. 43, Oct. 25, 1928, pp. 25-26.

Description of effect of plating on aluminum or duralumin with two different metals, first copper, then nickel or chromium, cobalt or cadmium; micrographic and physical characteristics. Paper presented before French Academy of Science, May 23, 1927.

ELECTRIC FURNACES

ANNEALING. Electric Heat Anneals Magnetic Iron. *Elec. World*, vol. 92, no. 20, Nov. 17, 1928, pp. 1002-1003, 1 fig.

Quality and Uniformity are assured in magnetic iron produced by Automatic Electric, Inc., Chicago, Ill., by use of electrically heated annealing furnaces; full automatic control is obtained through use of time clocks, which at predetermined hour establish control circuit through Leeds and Northrup potentiometer record controllers.

Modern Furnaces for Normalizing Sheets. *Heat Treating and Forging*, vol. 14, no. 11, Nov. 1928, pp. 1321-1324, 4 figs.

Furnace, constructed by Rust Engineering Co. of Pittsburgh, is 155-ft. long and divided into three primary zones, namely preheat, soaking, and cooling zones; preheat and soaking sections are approximately 75 ft. long, allowing 80 ft. for cooling zone; 20 burners on each side, burning oil through inducing burners with steam under high pressure as atomizing agent; shafts are heavy seamless tubes on which alloy disks, cast integral with long hub, are mounted 8 in. apart.

DEVELOPMENTS. Electric Furnaces, T. M. Pugsley. *Chem. Eng. and Min. Rev. (Melbourne)*, vol. 20, no. 240, Sept. 5, 1928, pp. 421-424.

Brief survey of progress in electric furnaces, since introduction by W. Siemens in early eighties; in 1910 there were 118 furnaces of all types, with 7 in use, 10 not working, and 38 being built; Heroult furnace most widely used in steel making; various modern types are mentioned, stressing Greaves-Etchell conducting-hearth type, and Ajax-Wyatt and Ajax Northrup induction furnaces.

ENAMELING. Electric Enameling Furnaces (Ein elektrischer Emaillierofen), H. Kalpers. *Giesserei (Duesseldorf)*, vol. 15, no. 42, Oct. 19, 1928, pp. 1060-1062, 3 figs.

Description of Brown, Boveri and Co. furnace which permits uniform heating of enamel ware and easy temperature adjustment; special attention was paid to development of temperature instruments.

HEAT TREATING. Conveyor Type Electric Furnaces, A. H. Vaughan. *Heat Treating and Forging*, vol. 14, no. 11, Nov. 1928, pp. 1328 and 1331-1332, 5 figs.

Five principal varieties of devices for propelling material to be heated through electric furnaces are discussed with reference to practical installations; they include: (1)

suspension conveyors using chains or other carrying means located outside furnace; (2) roller hearth-type furnaces with mechanical travel rolls; (3) apron conveyors similar to ones ordinarily used for bulk material handling; (4) belt conveyors using flexible metal belt for carrying material; (5) modifications of apron conveyor referred to above.

HIGH FREQUENCY. Induction Melting Furnace Producing Steel. *Heat Treating and Forging*, vol. 14, no. 11, Nov. 1928, pp. 1324-1325, 2 figs.

Description of 600-lb. high-frequency Ajax Northrup furnace installed at plant of Heppenstall Forge and Knife Co., Pittsburgh; installation is first in United States to cast steel in ingot form; h. f. current is generated in 150-kva. General Electric motor-generator set.

High Frequency Electric Furnaces, P. W. Hermann. *Radio*, vol. 10, no. 12, Dec. 1928, pp. 12-13, 5 figs.

Field of application for high-frequency induction furnace has been found in melting of precious metals and their alloys for dental use; construction of furnace unit; temperatures attained are in excess of 5000 deg. fahr.; furnace can be operated in vacuum or in highly reducing atmosphere.

New High-Speed Steel Made in Induction Furnace. *Iron and Steel of Canada (Gardenvale, Que.)*, vol. 11, no. 11, Nov. 1928, pp. 348-349.

Details of Ajax-Northrup high-frequency induction furnace in works of Edgar Allen Co., Sheffield, England; one hour completes 450 lb. heat; operation of furnace; advantages over crucible process; high-speed steel of extra durability is produced.

FERROMANGANESE

MANUFACTURE—RUSSIA. Manufacture of Ferromanganese in the Makiewka Works (Central Russia) [La fabrication du ferromanganese aux usines de Makiewka (Russie Meridonale)], V. G. Kotelnikoff. *Revue de Métallurgie (Paris)*, vol. 25, no. 10, Oct. 1928, pp. 541-556, 4 figs.

Blast furnaces and equipment described; firing up; raw materials used; operation of blast furnace; distribution of manganese in melt slag and gas; diagrams of operation; study of gas and dusts.

FOUNDRY INDUSTRY

Presidential Address, P. Nash. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 638, Nov. 8, 1928, pp. 335-336.

General discussion of work done by Brit. Cast Iron Research Assn. main divisions of work covered; education is dominant factor; cooperation with Continent and America; training facilities. Address before Brit. Cast Iron Research Assn.

Presidential Address to Scottish Branch, J. Longden. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 639, Nov. 15, 1928, pp. 360-362.

General discussion of foundry industry; inventor of oil-sand cores is unknown but author is convinced that he is responsible for success achieved by modern motor industry, for without oil-sand core many necessary castings would be difficult and costly, if not impossible, to make; refers to address by W. Bragg on Craftsmanship and Science.

FOUNDRY PRACTICE

The German Foundry Convention in Vienna (Der Deutsche Giessereitag in Wien). *Giesserei (Duesseldorf)*, vol. 15, no. 42, Oct. 19, 1928, pp. 1042-1047.

Account of meeting of Association of German Foundrymen in Vienna, Sept. 22 to 24, including visit to Budapest; brief reviews of papers read.

Quiet Pouring of Metals and Alloys (La coulée tranquille des métaux et alliages), P. G. Durville. *Revue de Métallurgie (Paris)*, vol. 25, no. 10, Oct. 1928, pp. 563-571, 4 figs.

Points out necessity of agitating molten metal as little as possible, treats of steel, copper and brass, and aluminum alloys during pouring process; also cast iron; greasing of ingot molds and effect on castings.

CORE CASTING. Urgent Cylindrical Casting Made in Cores, J. Edgar. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 640, Nov. 22, 1928, p. 384, 6 figs.

Use of cores not only speeds up job but enables it to be made cheaper than it would be in loam; core boxes necessary are framed core boxes, being open at both top and bottom; construction of strickles.

METAL MIXING. Melting Metals, M. G. Francis. *Brass World*, vol. 24, no. 11, Nov. 1928, p. 336.

Consideration of manner to proceed in production of alloy; more perfect union between components is secured by agitation of contents with stirring rod, most effect being wooden or carbon rod which promotes admixture without introduction of substances likely to contaminate mixture or modify properties; author has used deoxidizing agents such as boronic copper or phosphor copper as purifying agents for removing oxides.

PURCHASING. Foundry Purchasing, E. N. Simons. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 640, Nov. 22, 1928, p. 382.

Inspection of goods; storing goods: relation between buyer and storekeeper.

FUELS

DEVELOPMENTS. Fuels, Past and Prospective, S. W. Parr. *Fuels and Steam Power (A. S. M. E. Trans.)*, vol. 50, no. 8, Jan.-Apr. 1928, pp. 1-3.

Consideration relating to fuels as a whole which are general rather than specific in character; brief review of some of salient features connected with development of use of fuels.

FURNACES

FORGING. Speeds Forging Operations by Improved Furnace Design, F. W. Manker. *Iron Trade Rev.*, vol. 83, no. 21, Nov. 22, 1928, pp. 1314-1316, 4 figs.

Three main factors of forging process; description of group of billet-forging and heat-treating furnaces built by Surface Combustion Co. for Willys Overland Co., Toledo; layout of new Willys forge shop, and heat-treating plant; operation in forging furnaces automatic.

MELTING—GAS FIRED. The Use of Gas in Newspaper Offices. *Gas World (Lond.)*, vol. 89, no. 2307, Oct. 20, 1928, pp. 16-18 (supp.), 5 figs.

Description of modern-type melting furnace; advantages of gas firing, results of tests on Monometer melting furnaces, showing time required for melting metal in furnaces.

MELTING, OIL FIRED. Oil Furnaces for Non-Ferrous Metals. *Metal Industry (Lond.)*, vol. 33, no. 21, Nov. 23, 1928, pp. 496-497, 1 fig.

Description of various furnaces made by Monometer Manufacturing Co., including oil-fired metal-melting furnace, oil fired tilting-type furnaces, and non-crucible types of tilting furnaces.

REVERBERATORY. Furnace System for Chemical Reactions at High Temperatures (Ofensystem fuer die Ausfuehrung chemischer Reaktionen bei hoeheren Temperaturen), F. Meyer. *Chemiker-Zeitung (Kothen)*, vol. 52, no. 61, Aug. 1, 1928, pp. 599-600, 2 figs.

To obtain advantages of short furnace combined with heat economy, two or more small reverberatories are run in series, provision being made for direct firing of each furnace in turn and others being preheated by waste gases from that furnace; alternatively, hearth of long reverberatory may be subdivided by means of crosswalls and heating oil or gas supplied to each section in turn.

WALLS. Combustion Chamber Wall Design. *Eng. and Boiler House Rev. (Lond.)*, vol. 42, no. 5, Nov. 1928, pp. 248, 250 and 252, 3 figs.

Requirements of ideal furnace-wall construction are enumerated and details given of Bailey wall construction, main feature of which is its great strength to withstand fluxing action of ash and to reduce to lowest possible figure costs of furnace maintenance; it also provides additional heating surface.

GALVANIZED IRON

CORROSION. Investigation on the Corrosion of a Galvanized Iron Hot-Water Cylinder, H. F. Richards. *Iron and Steel Industry (Lond.)*, vol. 2, no. 2, Nov. 1928, pp. 45-46, 2 figs.

Investigation of corrosion in mild-steel cylinder ⅛ in. thick after two years' service; examination of corroded cylinder and conclusions drawn; failure due to corrosive action of water on zinc coating.

GEARS AND GEARING

METALLURGY. Metallurgical Problems of Transmission Gearing, E. F. Davis. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 6, Dec. 1928, pp. 831-852 and (discussion) 853-858, 12 figs.

Paper describes action of gear teeth in mesh and demonstrates why tooth failures cannot always be attributed to metallurgical defects; review of various stages in manufacture of good gears and attributing elements in success or failure of final products; brief description of modern furnace installations used in gear industry and advantages and disadvantages of different methods for heat-treating gears.

HIGH CARBON STEEL

DECARBURIZATION. Decarburization of High Carbon Steel In Reducing Atmospheres, J. J. Curran and J. H. G. Williams. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 6, Dec. 1928, pp. 809-825 and (discussion) 825-830, 27 figs.

Many instances have been observed of soft skin in high-carbon steel parts hardened under different conditions, but usually when precautions were taken to minimize scaling; tests indicate that carbonaceous packing mixtures may be either carburizing or decarburizing in their action; packing materials used to protect steel during heating probably are responsible for skin softness of steel after heat treatment. Bibliography.

HIGH SPEED STEEL

High Speed Steels: their Nature and Development, A. R. Page. *Iron and Steel Industry (Lond.)*, vol. 2, no. 2, Nov. 1928, pp. 57-59.

Great advances made during last 20 years in production and heat treatment of tool steels are discussed; cutting speeds; very high temperature must be used for hardening high speed steel to give it full range of properties of red hardness and resistance to tempering; results of tempering; selection of materials for press tools. Abstract of paper presented before Birmingham Met. Soc.

HEAT TREATMENT. Heating High Speed Steel to 2400 Degrees Fahr. in Molten Lead, W. C. Searle. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 6, Dec. 1928, pp. 927-930 and (discussion) 930-931, 3 figs.

Paper describes apparatus and method of heating steel to 2300 to 2400 deg. fahr. in molten lead; photomicrographs show structure obtained in specimens at 2200, 2300, and 2400 deg. fahr.

HOT BLAST STOVES

FUEL CONTROL. Fuel Control on Hot Blast Stoves, J. B. Fortune. *Inst. of Fuel—Jl. (Lond.)*, vol. 2, no. 5, Oct. 1928, pp. 116-126, 12 figs.

Hot blast stove functions as most important fuel-saving unit in blast-furnace plant; essential that combusion of gas be scientifically controlled during heating period of stove; composition, physical characteristics and combusion of blast-furnace gas; modern types of gas gun described; gas cleaning.

IRON

CORROSION. Corrosion of Iron (Ueber die Korrosion des Eisens), W. van W. Scholten. *Gas- u. Wasserfach (Munich)*, vol. 71, no. 36, Sept. 8, 1928, pp. 872-880.

Various factors which influence corrosion discussed: influence of carbon dioxide, oxygen and moisture, underwater rusting of iron, and effect of composition of iron; conclusion is that corrosion is electrochemical process, which is brought about by electromotive force which results between electrodes of different metals in same electrolyte or between electrodes of different solution pressure in metal in electrolyte.

CORROSION. On the Corrosion of Iron, H. Endo. *Tohoku Imperial Univ.—Sci. Reports (Tokio)*, vol. 17, no. 6, Sept. 1928, pp. 1111-1134, 14 figs.

Paper gives results of experiments on action of water, light, temperature, oxygen, acids and salt solutions, on corrosion of iron; first report of results of long series of experiments. (In English.) Report from Research Inst. for Iron, Steel and Other Metals.

IRON ALLOYS

ANALYSIS. Quick Method for Determination of Components of Iron Alloys by Means of Quantitative Spectroscopic Analysis (Die Schnellbestimmung von Legierungbestandteilen in Eisen durch quantitative Emissions-spektralanalyse), G. Scheibe and A. Neuhaeusser. *Zeit. fuer angewandte Chemie (Berlin)*, vol. 41, no. 45, Nov. 10, 1928, pp. 1218-1222, 8 figs.

Principles of spectroscopic analysis and its applications; curves for spectroscopic analysis of iron-silicon and iron-manganese alloys.

SILICON-ALUMINUM. Nitridation and Other Treatment of Silicon-Aluminum Iron Alloys (Nitridering och vidare bearbetning av kiselaluminiumjaern), T. Oertenblad. *Ingeniors Vetenskaps Akademien (Stockholm)*, no. 86, 1928, 80 pp., 22 figs.

Experimental study of silicon-aluminum-iron alloys obtained from Swedish materials by reducing in electric furnaces; treatment of nitrided product; solubility of silicon-iron in boiling sodium-hydroxide solution under pressure; spontaneous ignition of silicon hydride. (Summary in English.)

IRON CASTINGS

DEFECTS. Some Causes of Sponginess on the Upper Surfaces of Iron Castings, T. Butterworth. *Iron and Steel Industry (Lond.)* vol. 2, no. 2, No. 1928, pp. 43-44 and 46.

Causes of this vexatious defect are discussed in detail, and number of hints given to iron founders which will help them to combat nuisance; examination of spongy places; effects of air in mold and of pouring iron hot; pinhole defects; liberation of gases on solidification; heating of mold by metal gives good results; green sand molds more prone to sponginess.

GRINDING. Why Not Grind It? Economy Is Shown in Grinding Cast Iron Parts From Rough Castings. *Abrasive Industry*, vol. 9, no. 12, Dec. 1928, pp. 320-321, 4 figs.

Description of methods in plant of Diamond Machine Co., Providence, R. I., for grinding rough castings.

SHRINKAGE HOLES. Defects in Castings, P. A. Russell. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 640, Nov. 22, 1928, p. 384.

Discussion of paper published in Jan. 26, 1928, issue of journal.

IRON FOUNDRY PRACTICE

Practical Knowledge (Bekanntes praktisches Wissen). *Zeit. fuer die Gesamte Giesscreipraxis (Berlin)*, vol. 49, nos. 41 and 42, Oct. 7 and 14, 1928, pp. 342-343 and 350-352.

Practical pointers on iron foundry practice; evaluation of pig iron; wasters, their cause and prevention; design of ladles; molding sand; shrinkage of castings.

A Simple Casting with Some Unique Features, J. McLachlan. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 638, Nov. 8, 1928, p. 344, 10 figs.

Description of construction of bottom plate and of suitable half-lapped frame; mold prepared most satisfactorily by turnover method; to reduce condensation, brushing oil over faces of chill just before closing mold is most successful method.

IRON AND STEEL PLANTS

New Fabricating Plant in Philadelphia. *Iron Age*, vol. 122, no. 23, Dec. 6, 1928, pp. 1433-1434, 2 figs.

Details of new fabricating plant of American Steel Engineering Co., Philadelphia, which has been laid out with forethought as to expansion and in such a way as to facilitate handling steel in and out; fabricating work is done mostly upon basis of engineering in plant, covering all details both for structural steel and for reinforcing steel; materials handling is by means of traveling hoists running on I-beams.

FUEL ECONOMY. Fuel Control in Forge and Rolling Mill Practice, H. C. Armstrong. *Inst. of Fuel—Jl. (Lond.)*, vol. 2, no. 5, Oct. 1928, pp. 109-115, 6 figs.

Method of fuel control which has been adopted with some success in some large steel works; weekly data required for systematic control; fuel used; material heated or produced; furnace hours during which heating continues; necessary when compiling manufacturing costs to know how much fuel has been used per ton of product; thermal efficiency of reheating furnaces in common use; tests carried out to ascertain correct consumption; control of steam consumption as aid to fuel economy.

ONTARIO. Algoma Steel Works and Railways, Ontario. *Engineer (Lond.)*, vol. 146, no. 3799, Nov. 2, 1928, p. 494, 6 figs. on p. 488.

Plans of Lake Superior Corp. for future expansion of its plants and facilities in Algoma district; expects to spend $12,000,000; program includes construction of combination rail and structural steel up to 24-in. beams; new sheet mill capable of handling 40,000 to 50,000 tons of product; entire reconstruction of present merchant mill, etc.; combination skelp and strip mill, and conversion of Michipicoten Harbor into probably greatest coal-distributing port on North American Continent.

MAGNESIUM ALLOYS

EXPANSION. Thermal Expansion of Magnesium and Some of Its Alloys, P. Hidnert and W. T. Sweeney. *U. S. Bur. of Standards—Jl. of Research*, vol. 1, no. 5, Nov. 1928, pp. 771-792, 17 figs. partly on supplement plates.

Paper gives data on linear thermal expansion of 6 samples of cast and extruded magnesium and 11 samples of cast and extruded magnesium alloys over various temperature ranges; three types of apparatus were used and summary of available data by previous observers on thermal expansion of magnesium and some magnesium alloys is given; comparison of average coefficients of expansion of materials investigated.

MALLEABLE CASTINGS

WHITE-HEART. Whiteheart Malleable Tests, E. R. Taylor. *Foundry Trade Jl. (Lond.)*, vol. 30, no. 640, Nov. 22, 1928, p. 373.

Discussion of thin-walled malleable-casting tests; test bar of similar cross-section to actual work in hand would be most appropriate; in this case, test bars and articles they represent could be annealed together in efficient manner; manufacturer of thin-

walled goods would be enabled to carry out tests for tensile strength, elongation and bend, which at present are often omitted owing to unsuitability of standard test bar; engineering malleable castings meeting B.E.S.A. specification are satisfactory. From Brit. Cast Iron Research Assn.—Bul., Oct. 1928.

WHITE-HEART. Whiteheart Malleable Tests, E. R. Taylor. *Brit. Cast Iron Research Assn.—Bul. (Birmingham)*, no. 22, Oct. 1928, pp. 55-58.

Large branch of industry is concerned with production of small wares of malleable for which mechanical tests are never needed; these cannot be classed with engineering malleable castings required to stand up to definite service stresses; in latter class some more systematic measure of quality is necessary; thin-walled malleable castings; British Engineering Standards Assn. specification for whiteheart malleable is given; castings meeting these specifications are satisfactory.

MALLEABLE IRON CASTINGS

Malleable Cast Iron, C. H. Plant. *Iron and Steel Industry (Lond.)*, vol. 2, no. 2, Nov. 1928, pp. 53-55, 1 fig.

Melting of white-heart iron in cupola is described; cupola design is taken up with outline of things to guard against in proper working of cupola; importance of correct blast pressure upon which depends almost entirely economic and successful working of furnace; in regard to cokes, first iron should be down in 20 min. after blast is turned on; chemical changes and cupola gases.

MATERIALS TESTING

IMPACT. Some Principles of Investigation in Engineering Work, H. P. Philpot. *Junior Instn. of Engrs. (London)*, vol. 39, part 1, Oct. 1928, pp. 1-35, 19 figs.

Notched bar test in Izod pendulum machine and Charpy pendulum machine; comparison of test results obtained from two machines; investigations in connection with round test piece gave opportunities for finding out general characteristics of notched-bar test; investigation on design of combined burner for burning both liquid and gaseous fuels; describes briefly set of experiments carried out in connection with problem in design.

POROSITY. Approximate Determination of the Absolute Magnitude of Pores of Porous Materials (Nacherungsbestimmung der absoluten Groesse von Poren in poroesen Materialien), M. Rabinowitsch and N. Fortunatow. *Zeit. fuer angewandte Chemie (Berlin)*, vol. 41, no. 45, Nov. 10, 1928, pp. 1222-1226, 2 figs.

Principles of method based on difference in vapor tension of liquids in capillary and in non-capillary vessels; pore sizes of charcoal, graphite, caolin, porcelain, etc.

METALS

ANALYSIS. Investigation of Fine Structure of Metals and Alloys (Erforschung des Feinbaues der Metalle und Legierungen), F. Wever. *Zeit, fuer Metallkunde (Berlin)*, vol. 20, no. 10, Oct. 1928, pp. 363-370, 15 figs.

Structure of elementary metals and their distribution in periodic system of elements; relationship of properties to constitution of alloys, mixed crystals, and metal compounds; prospects for an atomic metallography.

CORROSION—SULPHUR MONOCHLORIDE. A Note on the Corrosive Action of Sulphur Monochloride, E. H. Harvey. *Chem. and Met. Eng.*, vol. 35, no. 11, Nov. 1928, p. 684.

Discussion of corrosion of pure metals by sulphur monochloride, a liquid chemical of importance in cold vulcanization of rubber and in connection with manufacture of mustard gas; presents table showing action of sulphur monochloride on certain pure metals. Bibliography.

CORROSION—THEORY. The Theory of Metallic Corrosion in the Lights of Quantitative Measurements, G. D. Bengough, J. M. Stuart and A. R. Lee. *Roy. Soc.—Proc. (Lond.)*, vol. 121, no. A 787, Nov. 1, 1928, pp. 88-121, 13 figs. partly on supp. plate.

Question of production of hydrogen gas is discussed; comparison between oxygen absorption and loss of weight methods of measuring corrosion; rate of evolution of hydrogen gas; relations between rate of corrosion and oxygen supply; factors which indicate total corrosion; influence of some surface factors; experimental conditions for estimating relative corrodibility.

FAILURES. Engineering Component Failures: Causes and Remedies. *Mech. World (Manchester)*, vol. 84, no. 2184, Nov. 9, 1928, pp. 438-440, 2 figs.

Indiscriminate mixing of scrap results in formation of alloys which are bad and liable to failures; failures from additions of lead and arsenic; hard spors of nearly pure iron in brass; overheating of nonferrous alloys is cause of greatest amount of trouble; failures in extruded metal and drop-stamped or hot-pressed non-ferrous alloys; failure of cast iron and aluminum alloys. (Concluded.)

HARDENING. Cold and Hot Working of Metals, W. Rosenhain. *Metallurgist (Supp. to Engineer, Lond.)*, Oct. 26, 1928, pp. 152-153.

Consideration of fact that even in harder metals of high melting point temperature is reached where metal no longer undergoes hardening as result of plastic deformation; author defines term by which state or condition of solid matter which is not truly crystalline can be denoted; hardening effect in all cases is regarded as depending upon retention of deformed crystal lattice in distorted or strained condition by resistance to return movement on part of those atoms which are brought into irregular (non-lattice) arrangement. (To be continued.)

TESTING. Rapid Determination of Endurance Strength (Die Schnellbestimmung der Dauerwechselfestigkeit), O. v. Bohuszewicz and W. Spaeth. *Stahl und Eisen (Duesseldorf)*, vol. 48, no. 43, Oct. 25, 1928, pp. 1505-1506, 5 figs.

Abstract of report no. 135 of Materials Committee of Verein deutscher Eisenhuettenleute previously indexed from Archiv fuer das Eisenhuettenwesen (Berlin), Oct. 1928.

TESTING. Long Duration Tensile Tests on Metals at High Temperatures, E. Honegger. *Brown Boveri Rev. (Baden)*, vol. 15, no. 11, Nov. 1928, pp. 315-320, 7 figs.

Discussion of early tests on metals at high temperature precedes description of Brown Boveri apparatus for making long duration tests; specimen enclosed in tubular electrically heated muffle; maximum load was 5000 kg.; ball bearings used throughout;

measurements taken on particularly elastic metals also; method of testing outlined.

METALS CUTTING

SAWS, COLD. The Process of Cutting of Metals with Cold Saws (Der Schneidvorgang bei der Zerspanung durch Kaltkreissaegen), A. Wallichs and H. Hemscheidt. *Maschinenbau (Berlin)*, vol. 7, no. 22, Nov. 15, 1928, pp. 1059-1064, 16 figs.

Theoretical analysis and experimental verification of effect of saw-tooth characteristics on power consumption. (Concluded.)

METALLOGRAPHY

Metallography Simplified for Practical Use in Shop, E. Preuss, G. Berndt, and M. v. Schwarz. *Iron Trade Rev.*, vol. 83, no. 22, Nov. 29, 1928, pp. 1375-1377, 4 figs.

Forging of iron-carbon alloys or steel containing carbon up to 1.7 per cent is considered; critical points and equilibrium diagrams of series of iron-carbon alloys; "metastable system" iron cementite, which is valid for forgeable iron-carbon alloys, considered. (Continuation of serial.)

METALLURGY

PATENTS. Reviews of Recent Patents, N. Littell. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 6, Dec. 1928, pp. 951-953, 3 figs.

Patents cover steel and its manufacture; process of improving qualities of nickel-beryllium alloy; annealing pot; art of refining iron and steel products; process of modifying aluminum-copper alloys; stable surface iron-chromium-silicon alloy; making synthetic pig iron; recuperator-type oil burner.

MOLDING PRACTICE

Molding of Hollow Wheels with Green Sand on Turnover-Type Molding Machine Without Special Attachment (Formen hohler Radkoerper mit gruenem Kern auf der Wendeplattenformmaschine, ohne besondere Vorrichtungen), A. Windhausen. *Giesserei (Duesseldorf)*, vol. 15, no. 44, Nov. 2, 1928, pp. 1109-1110, 6 figs.

Method of making triple-section molds in one operation is described.

MONEL METAL

APPLICATIONS. Monel Metal and its Applications. *Metal Industry (Lond.)*, vol. 33, no. 20, Nov. 16, 1928, pp. 463-466, 6 figs.

Monel metal is valued in engineering and industrial applications where strength and corrosion resistance are essential requirements; article gives brief account of firm of G. J. Weir, Ltd., of Glasgow, which has been responsible for development of use of this metal; Weir products, including Weir feed pump, are considered; history of alloy; strength at high temperature; dye and chemical industries; sanitary and culinary uses of monel metal.

NITRIC ACID, HANDLING

METALS. Nitric-Acid Production (Die Verwendung von Aluminium, Staehlen, VA-Metallen und Eisen-Silicium-Legierungen in der Salpetersaeuretechnik), B. Waeser. *Chemische Fabrik (Berlin)*, nos. 36 and 37, Sept. 5 and 12, 1928, pp. 529-530 and 544-546.

Behavior of metals toward nitric acid in various concentrations is compared, with reference to usefulness and service life of these metals when employed for nitric-acid retorts, evaporating dishes, and for pumps, valves, pipe, molds, reaction vessels, and the like to be used in handling nitric acid; comparative tables, showing rates of attack on metals by nitric acid, are given.

NONFERROUS FOUNDRIES

CLEANING. Rational Cleaning in Nonferrous Foundries (Ueber rationelles Putzen in Metallgiessereien), M. Schied. *Zeit. fuer die Giessereipraxis (Berlin)*, vol. 49, no. 44, Oct. 28, 1928 (Metal), pp. 173-175, 2 figs.

Description of methods and equipment of cleaning room of foundry of medium size making very small castings and some larger ones.

OIL ENGINES

METAL ANALYSIS. Engineering Materials Analyses. *Am. Mach.*, vol. 69, no. 22, Nov. 29, 1928, p. 851, 1 fig.

Analysis of materials in Winton 10 by 16-in. oil engine; aluminum and light alloys, brass, bronze, copper and cupro-nickel, iron, steel, purchased parts, and purchased units in engine are outlined. (To be continued.)

OPEN HEARTH FURNACES

CARBON BALANCE. Calculation of Carbon Balance of Metallurgical Furnaces, R. D. Pike. *Indus. and Eng. Chem.*, vol. 20, no. 12, Dec. 1928, pp. 1356-1361, 3 figs.

Paper describes application of stoichiometry to development of complete carbon balance, and incidentally fuel balance, of type of metallurgical furnace in which account is taken of possibility of leakage outwardly from certain parts of furnace of carbon-bearing gases; in development of method application is shown to furnace of open-hearth regenerative type.

DESIGN. Elements in Construction of Furnaces. *Iron Age*, vol. 122, no. 21, Nov. 22, 1928, pp. 1294-1296.

Review of discussion dealing with elements in construction of open-hearth furnaces, at Pittsburgh meeting of Open Hearth Committee of American Institute of Mining and Metallurgical Engineers; water cooling of furnaces; charging equipment; accounting for repair costs; organization of plant; keeping mud out of steel; Loftus brick keeps clean; Stevens open-hearth furnaces; value of large furnaces.

FUEL CONTROL. Fuel Control in Open Hearth Practice, J. L. Bentley. *Inst. of Fuel—Jl. (Lond.)*, vol. 2, no. 5, Oct. 1928, pp. 104-108, 8 figs. partly on supp. plates.

Particulars of results achieved at one works with which writer was connected; total combustible figures for each of gas samples; result of control of pressure and quality of producer gas is shown; graph showing complete working of charge and giving details of additions with analysis of slag and bath samples.

FUELS. The Use of Liquid Fuel in Open Hearth Furnaces, M. J. Conway. *Inst. of Fuel—Jl. (Lond.)*, vol. 2, no. 5, Oct. 1928, pp. 100-103, 8 figs. partly on supp. plates.

Relative cost of various open-hearth fuels is given in table; typical specification for heavy fuel oil adopted by U. S. Federal

Specifications Board; properties and tests; typical liquid-fuel installation is shown; some advantages to be obtained by use of liquid fuel.

OPERATION. Discussion of Open-Hearth Problems. *Iron Age*, vol. 122, no. 22, Nov. 29, 1928, pp. 1366-1368, 1 fig.

Discussion dealing with operation of open-hearth furnaces, taking place at Pittsburgh meeting of Open-Hearth Superintendents' Conference, is given; labor saving devices; characteristics of bottom-making material; automatic control of drafts; improved oil burners; regenerator brick; use of Dolomite machines; Austrian vs. American magnesite; ladle cars for hot metal.

RESEARCH. Open-Hearth Investigations of the United States Bureau of Mines, C. H. Herty, Jr. *Iron and Steel of Canada, (Gardenvale, Que.)*, vol. 11, no. 11, Nov., 1928, pp. 342-343.

Study of various problems connected with manufacture of steel; electric-furnace equipment crucibles; slags; determination of oxides in metals; inclusions in steel; abnormality in case-carburized steel.

PIPE MILLS

Automatic Seamless Pipe Mill, S. G. Koon. *Iron Age*, vol. 122, no. 22, Nov. 29, 1928, pp. 1353-1358, 10 figs.

Two independent automatic seamless pipe mills placed in Aliquippa plant of Jones and Laughlin Steel Corp., Pittsburgh, are described; avoidance of straight-line flow to achieve flexibility; six hot-working machines are staggered, with short transfer tables between them; two piercers used to avoid punishing steel; rounds are charged hot; operation of piercing machine; finishing the pipe.

PLATE MILLS

UNIVERSAL. Dominion Prosperity Starts Long-Idle Hamilton Plate Mill. *Can. Machy. (Toronto)*, vol. 39, no. 23, Nov. 15, 1928, pp. 31-32 and 69, 3 figs.

Description of only universal steel-plate rolling mill in Canada which is owned by Dominion Foundries and Steel, Hamilton, Ont., and which has been closed for seven years; universal plates up to 40 in. wide and sheared plate up to 60 in. wide rolled; new heating furnace to handle 20 tons per hr.; mill direct connected to 2200-hp. 600-volt d.c. reversing mill motor; details of approach table, run out and hot bed tables.

PRESSES, FORGING

HIGH SPEED. High-Speed Forging Presses. *Mech. World (Manchester)*, vol. 84, no. 2184, Nov. 9, 1928, pp. 435-437, 3 figs.

Description of forging presses of from 800 tons capacity up to those of 6000 tons capacity is given; comparison with steam hammer; utilization of waste heat in forge plants, and need for discrimination.

RAILS

BRAKING ACTION. Action of Intensive Braking or Sliding of Wheels on Tires and on Rails (l'action du freinage intensif ou du glissement des roues sur les bandages et sur les rails), E. Marcotte. *Revue Industrielle (Paris)*, vol. 58, no. 84, Nov. 1928, pp. 672-674, 8 figs.

Description of micrographic work; rails and tires of wheels which are set by braking effort and slide along rails; broken rails are analyzed.

ROLLING MILLS

ELECTRIC DRIVE. Electric Motors for Non-Reversing Rolling Mills of Single Speed (Les moteurs électriques de laminoirs irreversibles à une seule vitesse), Grivet. *Génie Civil (Paris)*, vol. 93, no. 17, Oct. 27, 1928, pp. 405-407, 1 fig.

Description of mills with and without flywheels; slippage; friction in roll bearings; speed of empty trains; advantages of elimination of flywheel.

SHEET METAL WORKING

X-RAY ANALYSIS. Study by X-Ray of Phenomena Accompanying Forming (Sur l'étude, au moyen des rayons X, des phénomènes accompagnant l'emboutissage), J. J. Trillat. *Chimie et Industrie (Paris)*, vol. 20, no. 4, Oct. 1928, pp. 618-622, 9 figs.

Investigation of action of metals which have been pressed or stamped, by x-rays; grain and distortion effect on them.

SILICON-MANGANESE STEEL

Silicon-Manganese Steel with Chromium Additions for Engineering Applications, A. B. Kinzel. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 6, Dec. 1928, pp. 866-875 and (discussion) 875-876.

These steels are highly suitable for engineering purposes and are susceptible to heat treatment; addition of hardening element, particularly one per cent chromium increases susceptibility to heat treatment and ease of application; silicon-manganese-chromium steels are stated to be superior to silicon-manganese or straight manganese steels similarly heat-treated.

SPRING METALS

FATIGUE. Fatigue and Corrosion-Fatigue of Spring Material, D. J. McAdam, Jr. *Am. Soc. Mech. Engrs.—Advance Paper*, no. 39a, for mtg. Dec. 3-7, 1928, 12 pp., 8 figs.

For spring steels ratio of endurance limit in tension-compression or repeated bend to tensile strength is 0.4 to 0.5; ratio of torsional endurance limit to tensile strength is 0.2 to 0.3; nickel-copper alloys can be obtained, by cold working, with tension-compression endurance limit more than 50,000 lb. per sq. in.; for copper-tin alloys, 5 per cent alloy, known as phosphor bronze, can be obtained with tension-compression endurance limit of 27,000 lb. per sq. in. in form of 1-in. round bars. Bibliography.

STEEL

CEMENTITE FORMATION. The Heat of Formation of Cementite, T. Watasé. *Tohoku Imperial Univ.—Sci. Reports (Tokio)*, vol. 17, no. 6, Sept. 1928, pp. 1091-1109, 2 figs.

Cementite was prepared by electrolyzing 2 per cent carbon steel and its heat of combustion was measured with Berthelot-Mahler's bomb calorimeter; writer has also been able to show experimentally that Ruff's procedure is defective in two points. (In English.)

HEAT TREATMENT. Principles of the Heat Treatment of Steel. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 6, Dec. 1928, pp. 893-926, 1 fig.

Outline prepared by metallurgical staff of Bureau of Standards; case hardening; alloy steels; high-speed tool steel; heat treatment of other alloys; definition of heat-treating terms. Bibliography of 20 pp.

HEAT TREATMENT. Pittsburgh Commercial Heat Treating Co. *Heat Treating and Forging*, vol. 14, no. 11, Nov. 1928, pp. 1333-1335. 2 figs.

Description of representative small plant devoted exclusively to heat treating and high-speed steel hardening; plant is prepared to heat-treat high-speed steels, alloy steels, and various types of carbon steels to conform to either hardness specifications or to definite physical properties; heat-treated parts can be handled up to 6000 lb.; large business done in treating helical springs; operations include all forms of regular and special annealing.

HEAT TREATMENT. The Thermal Treatment of Steel, P. R. Adams. *Can. Machy. (Toronto)*, vol. 39, nos. 21 and 22, Oct. 18 and Nov. 1, 1928, pp. 43-44 and 34, 67-69, 2 figs.

Oct. 18: Property which iron possesses of uniting with carbon; metallography; effects of heat treatment on structure and properties; decalescence point of any steel marks correct hardening temperature of that particular steel; why heating piece slightly more is sometimes necessary. Nov. 1: Normalizing, annealing, hardening, tempering, and case-hardening processes described with three factors which control results of processes, namely, composition, temperature, and rate of heating and cooling.

HEAT TREATMENT—CYANIDING. The Deterioration of the Cyanide Bath, V. E. Hillman and E. D. Clark. *Black and White (Metal Sec.)*, vol. 1, no. 5, Oct. 1928, pp. 27-29, 1 fig.

Immersion method is most commonly employed; sodium cyanide is used in varying degrees of concentration for carburizing purposes; fumes which arise from cyanide mixtures; determine effectiveness of cyanide hardening by resorting to file test; chemistry involved in decomposition of bath.

HEAT TREATMENT—DEFORMATION. Deformations Due to Temper in Hardened and Tempered Pieces (Déformations dues à la trempe dans les pieces cementées et trempées), R. Barat. *Revue de Metallurgie (Paris)*, vol. 25, no. 10, Oct. 1928, pp. 585-589, 9 figs.

Shows how pieces which have been case hardened may be deformed during tempering process; various cases are treated.

LOW CARBON—TESTING. Steel for Case-hardening—Normal and Abnormal Steel, S. Epstein and H. S. Rawdon. *U. S. Bur. Standards—Jl. of Research*, vol. 1, no. 3, Sept. 1928, pp. 423-466, 32 figs. partly on supplement plates.

Characteristics of so-called normal and abnormal microstructures of extreme types and intermediate gradations are described; quenching tests and hardness measurements for soft spots; Izod impact tests; normal and abnormal tool steel; causes of abnormality; practical aspects.

MAGNETIC PROPERTIES. Note on the Effect of Repeated Stresses on the Magnetic Properties of Steel, M. F. Fischer. *U. S. Bur. of Standards—Jl. of Research* vol. 1, no. 5, Nov. 1928, pp. 721-729 and (discussion) 729-732, 13 figs.

Possibility of detecting and following progress of fatigue crack by magnetic methods; it was found that magnetic changes produced by repeated stresses above endurance limit are not of type which can be associated with characteristic effect of crack transverse to direction of magnetization; material and apparatus; observations and results; summary and conclusion.

METALLOGRAPHY. The Hot Acid Etch Test for Steels, F. W. Rowe. *Iron and Steel Industry (Lond.)*, vol. 2, no. 2, Nov. 1928, pp. 37-40, 10 figs.

Standard routine tests often fail to disclose defects which later on may cause serious trouble; rapid and easily applied test which serves to reveal such faults is hot-acid etch test, using diluted sulphuric-hydrochloric acid mixture; hints on preparation of samples for subjection to this test are given, as well as notes on interpretation of appearances revealed.

STRESS LIMITS. Safe Stress Limits for Forged Steel, J. W. Urquhart. *Heat Treating and Forging*, vol. 14, no. 11, Nov. 1928, pp. 1282-1284.

Consideration of numerous instances of failures of steel products; application of stress limit figures; low permissible limit of stress is claimed by insurance authorities when steel components involved form part of machinery in motion, and are, therefore, under continuous changes of dynamic stress; steel structures at rest; crankshaft sand bending; effects of vibration.

TENSILE TESTING. Strain Markings in Mild Steel Under Tension, H. S. Rawdon. *U. S. Bur. Standards—Jl., of Research*, vol. 1, no. 3, Sept. 1928, pp. 467-485, 16 figs. partly on supp. plates.

Polished tension bars were examined during tension test to determine stress and corresponding elongation at which strain markings appear; materials and method; tension of polished specimens; effect of repeated loading; hardness of strained areas; X-ray examination; microstructure; comparison with aluminum alloy.

STEEL BALLS

MANUFACTURE. Steel Balls for Bearings (Bolas de acero para cojinetes) *Ingenieria International*, vol. 16, no. 11, Nov. 1928, pp. 532-534, 6 figs.

Processes and delicate industrial operations for manufacturing ball-bearing balls; corrections and tests; only perfect balls accepted.

STEEL CASTINGS

Steel Castings for Severe Service, J. H. Hall. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 639, Nov. 15, 1928, p. 362.

Reply to R. Hadfield's discussion of original paper; published in July 5, 1928, issue of same journal; quotation from Guillet showing that to him belongs credit for first recognizing great possibilities of pearlitic and sorbitic manganese steels for resisting shock and fatigue; limitations of manganese steel.

REQUIREMENTS. A Symposium on Steel Castings—Admiralty Requirements and X-Ray Investments, Sedgwick. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 639, Nov. 15, 1928, pp. 357-358 and (discussion) 359.

Admiralty requirements for material to be

suitable for production of castings to stand up to superheated steam; specifications for machinery castings; general characteristics of failures: blowholes, draws, porosity under pressure tests, contraction cracks, sand inclusions, scabbing and failure on physical tests; danger of laxity in patching; examination of castings by X-rays and by magnetic methods is being rapidly developed.

X-RAY ANALYSIS. A Symposium on Steel Castings—X-Ray Examination of Steel Castings, Pullin. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 639, Nov. 15, 1928, pp. 358-359 and (discussion) 359.

Technical details of X-ray work; limiting conditions; phenomenon of scattering; desensitized films used; X-ray crystal analysis and strain removal.

STEEL INGOTS

WHITE STAINS. Central White Stains in Ingots Rolled before Complete Solidification, Viteaux. *Int. Ry. Congress Assn.—Bul. (Lond.)*, vol. 10, no. 11, Nov. 1928, pp. 916-921, 10 figs.

Macrographic appearance of rails having white stain; metal in white central area completely differs in chemical composition from steel as originally poured; theory of Houbaer is summed up; series of macrographs taken from test pieces and from same bloom during rolling into French Railway standard 36-kg. (72.57 lb. per yard) rail. From Génie Civil.

STEEL MANUFACTURE

QUALITY CONTROL. Controlling the Quality of Steel Produced. *Iron Age*, vol. 122, no. 21, Nov. 22, 1928, pp. 1296-1298.

Review of discussion on quality control at Pittsburgh meeting of Open Hearth Committee of American Institute of Mining and Metallurgical Engineers; two years of research work on influence of iron oxide on metals by C. H. Herty, Jr.; difficulty in welding skelp steel; reducing pipe in special steels; cracking of ingots in rolling; titanium and aluminum in rimming steel; best slag conditions for low-carbon steel; report on Isley furnaces.

STRENGTH OF MATERIALS

Principles of the Theory of Strength of Materials (Die Grundlagen der theoretischen Festigkeitslehre), M. Ensslin. *V.D.I. Zeit. (Berlin)*, vol. 72, no. 45, Nov. 10, 1928, pp. 1625-1634, 18 figs.

Paper read at 1927 annual meeting of German Society for Testing Materials; discussion of ultimate strength from points of view of engineering and physics, ultimate strength in impact repeated stresses and under static load; ideal and imperfect state of engineering materials; single crystals; results of recent experiments for testing of theories of strength of materials compared with those obtained by Guest in 1900.

TOOL STEEL

Tool Steels, J. P. Gill. *Black and White (Metal Sec.)*, vol. 1, no. 5, Oct. 1928, pp. 30-34.

Specific effects of alloying elements; carbon tool steels; non-deforming oil-hardening steels; high-carbon low-tungsten tool steels; hot-worked die steels; low-carbon alloy tool steel; high-carbon high-chromium steels; high-speed steels. (Continuation of serial.)

CHEMICAL ANALYSIS. Tool Steels of the Chemical Analyses Shown Have Given Excellent Service, E. E. Thum. *Iron Age*, vol. 122, no. 21, Nov. 22, 1928, p. 1286.

Table given for chemical analysis of excellent tool steels.

TUNGSTEN CARBIDE. Carboloy and Tungsten Carbide Tools, S. L. Hoyt. *Am. Soc. Mech. Engrs.—Advance Paper*, no. 15, for mtg. Dec. 3-7, 1928, 4 pp.

Author points out that economic value of carboloy (trade name adopted by General Electric Co. for such material), is so great in many instances that it at once justifies its use; tungsten carbide may be classed as one of hardest materials, coming just below diamond and it has metallic rather than non-metallic nature; art of utilizing tungsten carbide is in its infancy; time and experience alone can teach how it is to be handled and how to delimit accurately scope of its applications.

WIRE, STEEL

DRAWING. Studies of Wire Drawing (Etudes sur la Tréfilerie), R. Papier, *Engineering (Lond.)*, vol. 126, no. 3278, Nov. 9, 1928, p. 577.

Review of two small booklets published by Usine, Paris; first part is second edition of treatise by author, and is summary of French practice in drawing of steel wire; second volume deals with varied shapes and proportions of nails and rivets; wire-drawing machinery.

PROPERTIES. Some Properties of Cold-Drawn and of Heat-Treated Steel Wire, S. H. Rees. *Iron and Steel Industry (Lond.)*, vol. 2, no. 2, Nov. 1928, pp. 51-52.

Brief abstract of paper read before Iron and Steel Inst., previously indexed from Iron and Coal Trades Rev. (Lond.), Sept. 28, 1928.

STRESSES. Influence of Various Factors upon the Internal Stresses Produced in Wire Drawing (Influence de divers facteurs sur les tensions internes d'étirage), A. Portevin. *Académie des Sciences—Comptes Rendus (Paris)*, vol. 186, no. 22, May 30, 1928, pp. 1463-1464.

Chief factors are: initial condition, reduction of diameter and speed of drawing, and subsequent machining or annealing; effects are less if reduction is made in several stages, and can be removed by annealing; as effects are confined to neighborhood of surface, machining will often remove most of strained metal, and for bar, turning it down leaves much less residual stress than boring it.

X-RAY ANALYSIS

EVALUATION. Methods for Evaluation of Diagrams (Verfahren der Diagrammauswertung), K. Herrmann. *Zeit. fuer Metallkunde (Berlin)*, vol. 20, no. 10, Oct. 1928, pp. 359-362, 11 figs.

Notes on evaluation of X-ray diagrams obtained according to rotating crystal, Debye Scherrer or Laue method; geometrical and mathematical principles are touched upon, but main emphasis is laid on graphic evaluation method.

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